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VOL. 21 JANUARY, 1929 NO. 1

## CHEMICAL AND MICROBIOLOGICAL PRINCIPLES UNDERLYING THE DECOMPOSITION OF GREEN MANURES IN THE SOIL[1]

SELMAN A. WAKSMAN[2]

### INTRODUCTION

Since the extent of virgin land which is still available for agricultural purposes especially for the growth of cultivated crops has been reduced to a minimum and since the soil which is now under cultivation is becoming constantly impoverished, the problem of improving agricultural land is becoming more and more pressing. The earlier idea of Thaer and others, including such prominent chemists as Davy and Berzelius, that soil "humus" is the most important plant nutrient received a decided setback in the work of de Saussure, Boussingault, and Liebig. It seemed, as a result of the contributions of these investigators, that all that was required to obtain a good crop yield was to supply to the growing plant a sufficient amount of minerals, as determined by an analysis of the plant ash, and of the necessary nitrogen in a combined form. These ideas have influenced the current teachings in regard to soil economy to

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This is the first of a series of three articles dealing with some of the principles underlying the utilization of natural organic materials on the farm. The second article will be devoted to artificial manures and the third to stable manure. There are two other types of organic matter which are of great importance in agriculture, namely, in peat and forest soils, but these represent very special cases and have been considered in detail elsewhere (13, 17). The use of organic fertilizers obtained as by-products in various industries, such as dried blood, cottonseed meal, leather meal, etc., 'll not be considered here, since the quantities of these materials utilized for this purpose at the present time are comparatively insignificant.

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such an extent that almost a century after Liebig first expounded them the fertilizer experts, in discussing the requirements of the soil for maximum plant production, consider only the nitrogen, phosphorus, potash and, if the reaction of the soil is acid, also the lime requirement of the soil, since these are the important elements that a crop requires or that may be essential for improving the chemical condition of the soil.

Here and there some soil chemists agree that organic matter may be required by certain soils, but since, in terms of chemical nutrients, it is a rather expensive source of N, P, and K, they are willing to concede that perhaps its favorable rôle in the soil may consist in offering "a food for the bacteria," thus making the organisms which are the active agents in the decomposition of organic matter in the soil and in the liberation of plant nutrients the chief beneficiaries of the specific treatment of the soil.

It became recognized as a result of the early studies of decomposition of organic matter in the soil that the carbon becomes liberated as $CO_2$ and the nitrogen as ammonia. Wollny established the fact that the decomposition of green manures in soil proceeds with great rapidity, the evolution of $CO_2$ being accompanied by an active formation of nitrates. Although the importance for plant growth of the nitrogen thus liberated in an available form has been known and appreciated for a long time, it is only within very recent years that attention has been paid, especially in Europe (Fischer, Bornemann, Lundegardh, Reinau), to the rôle of the stream of $CO_2$ which is constantly given off from the soil. It is claimed, as a result of these investigations, that the plants depend as much upon the $CO_2$ given off directly from the soil as upon the $CO_2$ of the atmosphere, although the latter originates also largely as a result of the activities of micro-organisms resulting in the decomposition of the soil organic matter. It is even claimed that the favorable effect of green manure upon crop growth is due largely to the $CO_2$ given off in the processes of decomposition.

There is no doubt that the recent rapid progress in the chemical fixation of nitrogen and in the manufacture of other fertilizers, combined with the extensive advertising campaigns of the fertilizer industries, on the one hand, and the simple principles of nutrition thereby involved, on the other, have had a great deal to do with this growing interest in inorganic fertilizers and a certain loss of interest in organic matter as a source of nutrients in the soil.

One need throw no reflection upon the important rôle played by inorganic fertilizers in soil economy and in agricultural practice.

However, one must call attention to the fact that, even with the rapidly growing consumption of inorganic sources of nitrogen and other artificial fertilizers on the farm, with the considerable attention which is given to it in the agricultural institutions, the actual amounts of N, P, and K which are applied to the soil at the present time in the form of inorganic fertilizers still comprise only a very small fraction of those quantities of these elements which are added yearly to the soil in the form of organic materials, including the various plant residues, green manures, stable manures, and the farm by-products, even if the organic matter is considered only as a source of these nutrient elements. One may add to this that organic matter plays an important function in the growth of higher plants as a source of $CO_2$, in improving the physical condition of the soil, such as moisture-holding capacity, temperature, etc., as well as in introducing certain rare elements usually not considered in the preparation of inorganic fertilizers. An efficient system of soil management should consist, therefore, in determining first what functions organic matter may play in soil processes and in plant growth, how it can be added to the soil in the most economical manner, then attempt to supplement this, where necessary and economically advisable, with artificial fertilizers.

Among the sources of organic matter added to the soil, green manures occupy a prominent place, not so much in the actual quantities used on the farms as in the potential possibilities that they offer to the farmer for the building up of his soil. The systematic investigations of Schulz-Lupitz in Germany were the first to lay a basis for the use of green manures in agricultural practice. These were at first considered largely from the point of view of increasing the organic matter content of the soil, but the discovery of the rôle of symbiotic bacteria in the fixation of atmospheric nitrogen by leguminous plants led to considerable emphasis upon the part played by green manures in increasing the nitrogen content of the soil. More recently, the green manures have come to be considered (4, 3)[3] as sources of $CO_2$ for the crops following them.

An extensive literature has accumulated on the use of green manures in agriculture. Unfortunately, many of these contributions are largely empirical in nature. The growth of vetch when followed by a crop of oats will result in an increase of so many bushels per acre, but when followed by a crop of wheat will yield an increase of so many bushels; the following year, when the rainfall, temperature, and other environmental factors are different, the results may

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be reversed or may be negative altogether. These studies offer no basis for generalizations, for establishing fundamental laws; they cannot even be interpreted when applied to other soils and other conditions; the tests have to be repeated all over again.

Considerable work has been done on the influence of green manures upon the physical condition of the soil, especially the "humus" content and moisture-holding capacity. Chemical studies dealing with the transformation of green manures in soil are few and far between. In most instances these are limited largely to a determination of the elementary constituents of the organic matter. This means very little, except for the nitrogen and ash figures; and even these vary considerably with the age and nature of plant, soil conditions, etc. Although the nitrogen problem is recognized as of the greatest importance in the use of green manures, there is only a limited amount of information in regard to the amount of nitrogen in the green manure crop which is made available to the next crop.

Microbiological studies concerning the transformation of green manure in soil are, with the exception of its influence upon the formation of nitrates, practically lacking altogether. The earlier idea concerning the rôle of worms and other animals in the decomposition of organic matter in soil has been later replaced by the theory that the oxidation processes carried out by soil micro-organisms or even chemical oxidation are largely responsible for the formation of "humus" in soil. Further studies pointed to the decomposition processes carried out by micro-organisms as leading to "humus" formation, and, as a recent author (9) expressed it, "humification, bacterial activities and nitrification" are closely related to one another. Legumes were usually found to be more effective upon the amount of nitrate nitrogen produced in soil than non-legumes and crops plowed under at a less mature stage of growth than the more mature crop (7).

The problem under consideration does not concern itself with the interpretation of the use of green manures, nor with outlining any system of farm management whereby green manures could be utilized to the greatest advantage, but is merely an attempt to present some of the principles involved in the transformation of green manures in the soil. This includes a study of their chemical composition and of the chemical and microbiological changes which take place when the green manure is plowed under in the soil.

The use of green manures as an efficient system of soil management has three distinct purposes, *viz.*, (a) To conserve the plant nutrients from being leached out from the soil by the drainage waters

during a time of the year when no crop is growing and when the weather conditions are favorable to the activities of soil micro-organisms; (b) to increase the supply of combined nitrogen in the soil by utilizing the activities of symbiotic nitrogen-fixing bacteria, i. e., by using various leguminous plants as green manures; and (c) to increase the organic matter content of the soil so as to counterbalance its steady diminution as a result of intensive cultivation of the soil.

Whatever primary consideration is given to the use of green manures in soil economy and whatever the nature of the plant selected for this purpose, attention must also be paid to the fact that the green manure crop must first be decomposed, after it has been plowed under, by soil micro-organisms, before the nutrients are made available for plant growth and before the organic residues become a part of the soil organic matter, thus increasing the amount of the so-called soil "humus" and imparting to the soil its specific chemical and physical characteristics.

To understand the mechanism and speed of liberation of nitrogen and other nutrients as a result of decomposition of a green manure crop, it is not merely sufficient to know the abundance of nitrogen and minerals in the plant materials comprising the green manure, not even their chemical make up, but it is important to gain also information concerning the nature of the other chemical complexes present in the green manure. These organic complexes may in themselves contain no nitrogen, phosphorus, or potash, as in the case of the celluloses and other carbohydrates, but their decomposition in the soil by micro-organisms influence markedly the amount and rapidity of liberation of those nutrients which are essential for plant growth. Hence, a knowledge of the liberation of N, P, K, etc., in the decomposition of the green manure crop involves a knowledge of the chemical composition of the plants and the nature of the decomposition processes brought about by micro-organisms.

The composition of the green manure crop will vary with the nature of the plant and with its age, which will in its turn also influence the decomposition processes. These also depend upon the physical and chemical soil conditions, such as reaction, temperature, and aeration, which influence the nature of the micro-organisms active in the decomposition of the plant material.

Wollny (21) was the first to recognize that the younger the plant added to the soil and the lighter and more aerated the soil, the more rapid are the decomposition processes. The period that elapses between the plowing under of the green manure and the planting of the new crop must be so timed as not to lose too much of the nu-

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Seelhorst (12) reported, for example, that the relation between the nitrogen in the new crop and in the drainage waters is 100:203 when the green manure is plowed under in the fall, and 100:123 when it is plowed under in early spring. Wollny also established the fact that substances with a high nitrogen content decompose more readily than those of a lower nitrogen content and that the further decomposition progresses the slower does it become and the more resistant is the residual organic matter to decomposition.

## CHEMICAL COMPOSITION OF GREEN MANURES

In the study of the chemical composition of green manures, one must clearly distinguish between the organic matter of young or immature plants which are usually employed as green manure and plant residues which are left after a crop has matured and been harvested; also between these and the organic matter of the soil or the so-called soil "humus." These three forms of organic matter are distinctly different in composition and in the rapidity of decomposition. A green manure must first of all be considered to be made up of certain plants which have been allowed to grow until a definite age during which period of time they have had an opportunity to assimilate a certain amount of nutrients from the soil and from the air and build up, by the aid of photosynthetic energy of the sun and its own complicated mechanism, a number of organic chemical substances. These organic complexes consist of the following elements: Carbon, which the plant obtains from the carbon dioxide of the atmosphere; hydrogen and oxygen which are obtained by the plant largely in the form of water; nitrogen derived from its inorganic forms in the soil or, in the case of leguminous plants, also partly or largely from the gaseous molecular nitrogen in the atmosphere through the agency of the symbiotic bacteria; sulfur and phosphorus obtained from soluble inorganic salts of these in the soil; certain other minerals, especially potassium, calcium, and iron, and the less important sodium, chlorine, silicon, and magnesium, as well as traces of a number of other elements.

The elements C, H, O, N, S, and P are present in the plant largely in organic combinations, which make up 92 to 98% of the plant constituents. In view of the fact that plants cannot assimilate these elements in organic forms (except in mere traces), these 92 to 98% of the plant constituents have to be first decomposed again to simple forms in the soil before the new plants of the following crop can utilize them for the building up of new cell substance. Since these

elements, especially N, C, P, K, S, are present in the soil in an available form only in minimum quantities, it is of importance to learn the mechanism of disintegration of the complex plant materials into their constituent elements or simple compounds, namely, into forms available for the growth of other plants.

To understand this it must be recognized first of all that we are dealing here with complex substances and complicated reactions, which, however simple their exposition and interpretation, involve various chemical considerations which must be clearly understood if the subject is to be made a part of the agricultural teachings.

For the sake of convenience, the various chemical plant constituents can be divided into the following groups.

1. *Water-soluble constituents.*—These include the most readily available nutrients, both for the growth of the plant and for the growth of micro-organisms, when the plant is undergoing decomposition. These constituents comprise a number of organic and inorganic substances, such as the sugars, various glucosides, amino acids, and certain simple proteins among the former, while the latter include nitrates, phosphates, sulfates, chlorides, potassium salts, etc. This group of plant constituents is highest when the plant is young, making up as much as 40% of the dry matter of the total plant material. This percentage decreases with age, so that mature plants may contain only about 5% of water-soluble constituents, these proportions depending of course also on the nature of the plant and available nutrients.

2. *Ether and alcohol-soluble constituents.*—They comprise the fats and oils, waxes and resins, tannins, terpenes, alkaloids, and various pigments. They make up only a small portion of the plant, usually 2 to 6%, grown for green manuring purposes.

3. *Celluloses.*—These form in most plants the largest single group of constituents, ranging from 15 to 40% of the dry weight of the plant material. They are polysaccharides which serve the function of protective substances in the plant and they are not hydrolyzed by dilute acids and alkalies. They are rapidly decomposed, however, under certain conditions by various specific bacteria and fungi.

4. *Hemicelluloses.*—These and other carbohydrates, not included in the sugars and in the celluloses, play a function of both reserve and protective substances in plants. They are also polysaccharides of the pentose or hexose group and are hydrolyzed by dilute acids. They make up 10 to 30% of the plant constituents. Some of them are decomposed even more rapidly than the celluloses, while others are more resistant.

5. *Lignins.*—Lignins are the so-called incrusting substances in plants. Both lignins and celluloses, which form in the plant complexes of a chemical or physical nature known as ligno-celluloses, are low in young plants and increase in proportion with the age of the plant, both in total quantity and in relation to the other plant constituents. The lignins, which make up 5 to 30% of the dry plant material, are most resistant to decomposition in the soil.

6. *Proteins.*—These substances play an important function in the nutrition of the plant and in the decomposition of the plant residues in the soil, since they are largely the carriers of the important element nitrogen, as well as of some of the phosphorus and sulfur. In view of the fact that the nitrogen is liberated in the form of ammonia, as a result of the decomposition of the proteins, it was usually assumed that it is sufficient to measure the rapidity of ammonia accumulation from proteins to have a fair conception of the mechanism and rapidity of protein decomposition in the soil. However, we come to recognize now that, in the presence of celluloses and hemicelluloses, which are readily used as sources of energy by micro-organisms, a part, if not all, of the nitrogen which is liberated in the decomposition of the proteins may be reassimilated by the soil micro-organisms and changed into microbial cell substance.

The nitrogen (or protein) content of plants is high at an early stage of growth and decreases with an increase in the maturity of the plants, frequently from 18 % protein in the young plants to about 1.2 to 1.5% in the mature straw. Young rye, barley, and wheat plants may contain at an early stage of growth 2 to 3% of nitrogen or as much as the leguminous plants do. Even if the cereal plants obtain their nitrogen from the soil and the legumes partly from the air, the fact that the rye plant will assimilate the soil nitrates at a time of year when they are subject to leaching may place the question on a different basis for comparing the value of different plants for green manuring purposes.

7. *Minerals.*—These include phosphates, sulfates, chlorides, nitrates, and silicates of potassium, calcium, magnesium, iron, aluminum, etc., some of which are water-soluble and others insoluble. They form the ash content of the plant, although some are also present in the proteins (S, P). They make up from 1 to 12% of the total plant constituents. They are high in young plants and diminish, in proportion to the other plant constituents, with maturity of the plants. The nature of the minerals in the young and old plants differs not only quantitatively but also qualitatively, the soluble minerals predominating in the younger plants and the insoluble in the older plants.

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1. *Water-soluble constituents.*—These include the most readily available nutrients, both for the growth of the plant and for the growth of micro-organisms, when the plant is undergoing decomposition. These constituents comprise a number of organic and inorganic substances, such as the sugars, various glucosides, amino acids, and certain simple proteins among the former, while the latter include nitrates, phosphates, sulfates, chlorides, potassium salts, etc. This group of plant constituents is highest when the plant is young, making up as much as 40% of the dry matter of the total plant material. This percentage decreases with age, so that mature plants may contain only about 5% of water-soluble constituents, these proportions depending of course also on the nature of the plant and available nutrients.

2. *Ether and alcohol-soluble constituents.*—They comprise the fats and oils, waxes and resins, tannins, terpenes, alkaloids, and various pigments. They make up only a small portion of the plant, usually 2 to 6%, grown for green manuring purposes.

3. *Celluloses.*—These form in most plants the largest single group of constituents, ranging from 15 to 40% of the dry weight of the plant material. They are polysaccharides which serve the function of protective substances in the plant and they are not hydrolyzed by dilute acids and alkalies. They are rapidly decomposed, however, under certain conditions by various specific bacteria and fungi.

4. *Hemicelluloses.*—These and other carbohydrates, not included in the sugars and in the celluloses, play a function of both reserve and protective substances in plants. They are also polysaccharides of the pentose or hexose group and are hydrolyzed by dilute acids. They make up 10 to 30% of the plant constituents. Some of them are decomposed even more rapidly than the celluloses, while others are more resistant.

5. *Lignins.*—Lignins are the so-called incrusting substances in plants. Both lignins and celluloses, which form in the plant complexes of a chemical or physical nature known as ligno-celluloses, are low in young plants and increase in proportion with the age of the plant, both in total quantity and in relation to the other plant constituents. The lignins, which make up 5 to 30% of the dry plant material, are most resistant to decomposition in the soil.

6. *Proteins.*—These substances play an important function in the nutrition of the plant and in the decomposition of the plant residues in the soil, since they are largely the carriers of the important element nitrogen, as well as of some of the phosphorus and sulfur. In view of the fact that the nitrogen is liberated in the form of ammonia, as a result of the decomposition of the proteins, it was usually assumed that it is sufficient to measure the rapidity of ammonia accumulation from proteins to have a fair conception of the mechanism and rapidity of protein decomposition in the soil. However, we come to recognize now that, in the presence of celluloses and hemicelluloses, which are readily used as sources of energy by micro-organisms, a part, if not all, of the nitrogen which is liberated in the decomposition of the proteins may be reassimilated by the soil micro-organisms and changed into microbial cell substance.

The nitrogen (or protein) content of plants is high at an early stage of growth and decreases with an increase in the maturity of the plants, frequently from 18 % protein in the young plants to about 1.2 to 1.5% in the mature straw. Young rye, barley, and wheat plants may contain at an early stage of growth 2 to 3% of nitrogen or as much as the leguminous plants do. Even if the cereal plants obtain their nitrogen from the soil and the legumes partly from the air, the fact that the rye plant will assimilate the soil nitrates at a time of year when they are subject to leaching may place the question on a different basis for comparing the value of different plants for green manuring purposes.

7. *Minerals.*—These include phosphates, sulfates, chlorides, nitrates, and silicates of potassium, calcium, magnesium, iron, aluminum, etc., some of which are water-soluble and others insoluble. They form the ash content of the plant, although some are also present in the proteins (S, P). They make up from 1 to 12% of the total plant constituents. They are high in young plants and diminish, in proportion to the other plant constituents, with maturity of the plants. The nature of the minerals in the young and old plants differs not only quantitatively but also qualitatively, the soluble minerals predominating in the younger plants and the insoluble in the older plants.

TABLE 1.—*Chemical composition of a series of plant materials on air-dry basis.*

| Chemical complexes | Young rye plants | Mature wheat straw | Soybean tops | Alfalfa tops | Young corn stalks | More mature corn stalks | Young pine needles | Old pine needles | Oak leaves, green | Oak leaves, mature, brown |
|---|---|---|---|---|---|---|---|---|---|---|
| | % | % | % | % | % | % | % | % | % | % |
| Ether-soluble portion | 2.35 | 1.10 | 3.80 | 10.41‡ | 3.42‡ | 5.94‡ | 7.65 | 23.92‡ | 7.75 | 4.01 |
| Water-soluble portion | 29.54 | 5.57 | 22.09 | 17.24 | 28.27 | 14.14 | 13.02 | 7.29 | 22.02 | 15.32 |
| Hemicelluloses | 12.67† | 26.35† | 11.08† | 13.14 | 20.38 | 21.91 | 14.68 | 18.98 | 12.50 | 15.60 |
| Celluloses | 17.84 | 39.10 | 28.53 | 23.65 | 23.05 | 28.67 | 18.26 | 16.43 | 15.92 | 17.18 |
| Lignins | 10.61 | 21.60 | 13.84 | 8.95 | 9.68 | 9.46 | 27.63§ | 22.68 | 20.67 | 29.66 |
| Protein* | 12.26 | 2.10 | 11.04 | 12.81 | 2.61 | 2.44 | 8.53 | 2.19 | 9.18 | 3.47 |
| Ash | 12.55 | 3.53 | 9.14 | 10.30 | 7.40 | 7.54 | 3.08 | 2.51 | 6.40 | 4.68 |
| Total accounted for | 97.82 | 99.35 | 99.52 | 96.50 | 94.81 | 90.10 | 92.85 | 94.00 | 91.44 | 89.92 |

*Protein figure is obtained by subtracting water-soluble nitrogen from total nitrogen, then multiplying difference by 6.25.

†Pentosans only.

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§The higher lignin content in the younger needles is due largely to the fact that this preparation has not been extracted with alcohol.

In these seven groups of complexes we can account for practically 90 to 96% of the plant constituents. No attempt need be made to determine those chemical substances which are present in quantities of less than 1%.

Table 1 gives a series of analyses of a number of plants in a green or mature stage, while Table 2 gives the composition of the rye plant at different stages of growth.

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| Chemical complexes | I, 10–14 inches high | II, just before head formation (exsertion of spikes) | III, just before bloom (stems and leaves) | IV, mature plants (stems and leaves) |
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| Ash | 7.66 | 5.90 | 4.90 | 3.90 |
| Total nitrogen | 2.50 | 1.76 | 1.01 | 0.24 |

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The results show very definitely that, with an increase in age of plant, there is a decrease in the water-soluble material; in the minerals, both total and water-soluble; and in the nitrogen, both total and water-soluble. This is accompanied by an increase in the hemicelluloses, celluloses, and lignins. A similar change in the composition of the plant with age has been found not only in the Gramineae (2), but also in the Leguminosae (6) and in other plants.

## DECOMPOSITION OF GREEN MANURES

The abundance of the various chemical groups in the plant modify largely the rapidity of its decomposition. Three indices may be used for measuring the rate of this process, *viz.*, (a) liberation of available nitrogen as ammonia, which is soon changed to nitrate. This is an indirect index, since it tells nothing of the various processes taking place in the decomposition of the plant material and considerable time may elapse before any ammonia or nitrate is formed at all, while a large part of the plant may have already undergone decomposition. (b) Liberation of $CO_2$, a very good index for measuring the sum total of the decomposition processes (10), but supplying little information concerning the nature of the plant constituents

which are being decomposed. (c) The determination of the disappearance or transformation of the various chemical groups mentioned above in the plant material, with the progress of decomposition, by a method outlined elsewhere (13).

Using nitrate formation as an index of the rapidity of decomposition of green manure, Whiting (19,20) came to the conclusion that the amount of water-soluble constituents, especially of the nitrogen, determines largely the speed of nitrate formation, even more so than the total nitrogen in the plant. Potter and Snyder (10), using $CO_2$ evolution as an index of the decomposition of green manure, found that the earlier claims concerning the favorable effect of the addition of a small amount of stable manure with the green manure upon the decomposition of the latter were not substantiated. The addition of lime had, however, a decided favorable effect upon the process.

When the decomposition of clover roots was compared (18) with that of timothy roots, it was found that during the first 13 days considerably more $CO_2$ was given off from the clover than from the timothy residues. After 13 days, the process was reversed and more $CO_2$ was given off from the latter than from the former. The nitrates in the soil disappeared in both cases, although they reappeared sooner and in considerably larger quantities in the soil receiving the clover roots than in the case of the timothy roots. This is not due to any inherent difference in the effect of timothy and clover upon nitrate depression, but to the higher content of water-soluble constituents and of nitrogen in the clover than in the timothy residues. As a result of the larger content of water-soluble constituents in the clover roots, more $CO_2$ was given off as soon as they underwent decomposition. When these decomposed, the micro-organisms attacked the insoluble proteins, hemicelluloses, and celluloses, more nitrogen being thereby liberated from a substance richer in proteins (clover root) and more nitrogen being consumed in the case of a substance (timothy roots) richer in hemicelluloses and celluloses.

The following results of Waksman and Tenney (15) may serve to illustrate the importance of a careful knowledge of the plant composition upon the speed of its decomposition and the liberation of nitrogen in an available form. These results were obtained in the study of decomposition of various preparations of the rye plant grown in the field and harvested at different stages of growth, the analyses of which were given in Table 2. Two-gram portions (on a dry weight basis) of each preparation were added to 100 grams of soil and incubated for 27 days. The results (Table 3) show very distinctly

that with an advance in the age and maturity of the plant there is a diminution in the speed of decomposition, as shown by the evolution of $CO_2$. More important yet, while the decomposition of the younger plant was accompanied by a rapid liberation of the nitrogen from the green manure in the form of ammonia, the decomposition of the more mature plants did not result in the liberation of the nitrogen, but there was an actual consumption by the soil micro-organisms of the inorganic nitrogen added to the soil in the form of a salt. Had this nitrogen not been added, the decomposition would have been much slower.

TABLE 3.—*Rapidity of decomposition of rye at different stages of growth and liberation of available nitrogen.*

| Sample No. | $CO_2$ given off in mgm of C | Nitrogen liberated as ammonia in mgm of N | Nitrogen consumed from ammonium salt added to soil in mgm of N |
|---|---|---|---|
| I | 286.8 | 22.2 | —— |
| II | 280.4 | 3.0 | —— |
| III | 199.5 | 0 | 7.5 |
| IV | 187.9 | 0 | 8.9 |

A detailed discussion of these results elsewhere (15) has shown that the rye plants that were sampled the second time, or while they were still very young, when submitted to decomposition by micro-organisms for about four weeks, lost 81.5% of pentosan, 76.6% of cellulose, but still contained 31% of protein. The mature rye straw, or the material obtained in the fourth sampling, when submitted to decomposition for about four weeks, lost a large part of its cellulose, while the protein content did not diminish at all but even increased. Actually there was found at the end of the decomposition period three times as much protein than at the beginning. This is due to the fact that the pentosans and celluloses, excellent sources of energy for soil micro-organisms, enabled these organisms to synthesize considerable cell substance, the nitrogen required for this purpose being derived from the inorganic sources of nitrogen added to the organic matter due to the low content of this element in the mature rye straw.

However, not all plants will behave alike when undergoing decomposition. Some plants will decompose more slowly with an advance in age, due to a diminution in the water-soluble substances and total nitrogen and an increase in the celluloses and lignins, while other plants show no marked decrease in the rapidity of decomposition with an increase in age, due to the fact that no such marked changes take place in the composition of the plant. This was found by Bal (1) to be the case for certain plants used as green manure in

India. The first type of plant grows rapidly and with age there is a constant widening of the carbon-nitrogen ratio. In the second type of plant, the carbon-nitrogen ratio remains the same throughout the different stages of growth or changes only slowly.

These results point quite definitely to the fact that in deciding upon a plant as a source of green manure we must first of all consider its chemical composition, not in terms of its elements as C, H, O, N, etc., but in terms of definite chemical complexes. Secondly, the rapidity of the decomposition of the plant materials and the relation of the nitrogen content of the plant to that of the other plant constituents, especially the hemicelluloses and celluloses, must be given consideration. The lignins decompose much more slowly and hence will not play such an important rôle in the nitrogen transformation, although a high lignin content will delay the rapidity of cellulose decomposition, while the water-soluble substances can be used as sources of energy by nitrogen-fixing bacteria, hence their abundance will not influence considerably the nitrogen transformations, although it may in certain cases, especially in the presence of nitrate in soil.

This can be further illustrated (16) by the decomposition of alfalfa tops, more mature corn stalks, and mature oak leaves, the composition of which is given in Table 1. Sufficient moisture was added (200%) to 5-gram portions of these organic materials to make conditions aerobic and a suspension of fresh soil was used for inoculation. The $CO_2$ produced in the process of decomposition was determined and, after 28 days' incubation, the residual material was analyzed (Table 4). The corn stalks and the oak leaves received nutrients in the form of available nitrogen, phosphorus, and potassium, $(NH_4)_2HPO_4 + K_2HPO_4$.

TABLE 4.—*Decomposition of alfalfa tops, corn stalk, and oak leaves in 28 days at 25° C.*

| | Alfalfa | Corn stalks | Mature oak leaves |
|---|---|---|---|
| Water-soluble, % | 50.0 | 36.0 | 33.0 |
| Hemicelluloses, % | 43.0 | 33.0 | 55.0 |
| Celluloses, % | 74.0 | 38.0 | 72.0 |
| $CO_2$ given off, mgm | 718.0 | 870.0 | 327.0 |
| Nitrogen liberated, mgm $NH_3$ | 24.2 | —— | —— |
| Nitrogen consumed, mgm $NH_3$ | —— | 30.8 | 20.2 |

While the decomposition of the alfalfa resulted in the liberation of some of the nitrogen as ammonia in a period of four weeks, the decomposition of corn stalks and of oak leaves led to a considerable consumption of available nitrogen and its transformation into microbial cell substance.

## DISCUSSION

The two most important problems to be considered in the decomposition of green manures in the soil are the speed of liberation of nitrogen in an available form, and the amount of organic matter left in a residual form which goes to increase the soil organic matter or soil "humus." The liberation of phosphorus and other minerals will accompany or even precede the liberation of the nitrogen, while the evolution of $CO_2$ is a phenomenon definitely established which does not involve any complicated questions, except that it takes place abundantly when the soil is well aerated.

To be able to understand the nature and speed of nitrogen liberation in the decomposition of green manures (as well as of plant residues in general, as shown later, when additional nitrogen may be required to bring about active decomposition), one must consider in detail the nature and metabolism of the micro-organisms which are active in the decomposition processes. Until these problems are understood, the practice of green manures can be but a hit and miss affair. There is no wonder, therefore, that when Wollny attempted to introduce a system into the subject of decomposition of organic matter in the soil he had to prepare a text of microbiology. Unfortunately, neither the chemical composition of the plant substances nor the metabolism of the organisms were as well understood then as they are at the present time, so that his work remained only a splendid introduction to the subject under consideration.

Without going into any detailed review of the nature of the micro-organisms concerned in the decomposition of organic matter in soil and their metabolism, or the mechanism of chemical transformation of the individual plant constituents, some general principles may be laid down which will help to introduce the subject under consideration.

As pointed out above, the organic plant constituents can be broadly divided into six general groups, as follows: (a) The water-soluble substances, largely sugars, organic acids, higher alcohols, glucosides, to some extent starches, amino acids, etc; (b) the fats, oils, waxes, resins, terpenes, etc.; (c) the hemicelluloses; (d) the celluloses; (e) the lignins; and (f) the proteins. The decomposition of each of these groups by micro-organisms will involve different considerations, both in regard to the nitrogen transformation, especially the liberation of a larger or smaller part of this nitrogen in an available form, and the residual organic matter which goes to increase the amount of soil "humus."

The metabolism of an organism involves transformations of energy and synthesis of cell substance. Since most of the soil micro-organ-

isms, with the exception of the algae and autotrophic bacteria, are heterotrophic in nature, i. e., require an organic substance as a source of energy, the green manure plowed under will offer an available source of energy for the activities of a great many organisms present in the soil. It should not be assumed, however, that the plant substances making up the green manure will be attacked as a whole. On the contrary, some plant constituents will be attacked very rapidly and others only very slowly or not at all under certain conditions. The nature of the composition of a plant, therefore, will influence the nature and speed of its decomposition. Different micro-organisms are capable of attacking the various chemical complexes of the plant with a different rapidity and bring about different chemical reactions. Different soil conditions which bring about differences in the soil population, therefore, will also influence the nature of the decomposition processes.

A part of the carbon complexes will be decomposed to $CO_2$ or intermediate products (organic acids, alcohols, etc.) to yield energy for the organisms, while a part of the organic carbon will be used by the micro-organisms for the synthesis of their cell substance. The ratio between the organic matter decomposed and the amount of cell substance thus synthesized varies with the organism and with the environmental conditions. In the case of fungi, for example, as much as 30 to 50% of the carbon of the organic matter decomposed may be used for the synthesis of fungus mycelium and spores. In the case of aerobic bacteria, 20 to 40% of the carbon may thus be utilized, while in the case of anaerobic bacteria only 2 to 5% of the carbon of the organic matter decomposed is built up into bacterial cell substance. This means that if 1,000 pounds of fresh green plant material, containing 80% of moisture is decomposed completely by fungi, about 300 to 500 pounds of fungus mycelium and spores are produced, assuming that the moisture content of these is also 80% and that the carbon content of the organic matter and of the fungus cell substance is the same.

In view of the fact, however, that microbial cell substance contains a definite amount of nitrogen and phosphorus, the speed of decomposition of the organic matter will be controlled by the amount of available nitrogen and phosphorus. In the above illustration 300 to 500 pounds of moist fungus mycelium (or 60 to 100 pounds dry material) will contain 2.0 to 5.0 pounds of nitrogen. If the original organic matter can be completely decomposed and if it contains this amount of nitrogen, the process of decomposition will not be accompanied by any liberation of nitrogen in an available form. This will take place only when the fungus mycelium itself will begin to

undergo decomposition. However, the fact that plant substance is made up of a number of chemical groups, some of which will decompose more readily than others, will further complicate the problem.

The six groups of chemical complexes enumerated above will decompose in the following manner: The water-soluble constituents are decomposed most rapidly and completely. Since the nitrogen-fixing bacteria are capable of using most of these substances as sources of energy, the lack of available nitrogen will in no way limit the rapidity of their decomposition, although the presence of nitrate in the soil will stimulate the development of fungi and various bacteria which rapidly assimilate the nitrate, using the water-soluble substances as sources of energy. Since green manures may contain as much as 20 to 40% of the total dry matter in a water-soluble form, the rapidity of its decomposition, especially when $CO_2$ is used as an index, can thus be readily understood.

The second group, or the fats, waxes, tannins, etc., undergo only slow decomposition and, when they are especially abundant, as in pine needles and certain leaves, they may even interfere with the decomposition of the other plant constituents. However, they are not very abundant in the plants which are commonly used for green manuring purposes and need not influence materially the nitrogen liberation, although they may, when present in any abundance, influence the amount of the soil "humus" produced.

The hemicelluloses and celluloses may be considered together, although some of the pentosans decompose more rapidly than the celluloses and some hemicelluloses decompose less rapidly. These two groups are characterized by being free from nitrogen, by being fairly rapidly decomposed by micro-organisms, and by not being used as sources of energy for nitrogen-fixing bacteria.[4] Hence, the fungi and bacteria which decompose these two groups of plant constituents require a source of nitrogen. The more abundant these two groups are, the more nitrogen will be required. Since the hemicelluloses and celluloses may make up 60 to 65% of the mature plants and only 40% of the younger plants, their decomposition in the green manure will involve less nitrogen consumption than in the more mature plant.

The lignins form a group of plant constituents which are most resistant to decomposition. Their abundance in plant residues will even protect somewhat the celluloses against decomposition. Since the lignin content of the plant increases with age, the greater re-

[4]This is definite in the case of celluloses but still remains to be determined for hemicelluloses.

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| | % | % | % | % | % | % | % | % | % | % |
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| Protein* | 12.26 | 2.10 | 11.04 | 12.81 | 2.61 | 2.44 | 8.53 | 2.19 | 9.18 | 3.47 |
| Ash | 12.55 | 3.53 | 9.14 | 10.30 | 7.40 | 7.54 | 3.08 | 2.51 | 6.40 | 4.68 |
| Total accounted for | 97.82 | 99.35 | 99.52 | 96.50 | 94.81 | 90.10 | 92.85 | 94.00 | 91.44 | 89.92 |

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However, not all plants will behave alike when undergoing decomposition. Some plants will decompose more slowly with an advance in age, due to a diminution in the water-soluble substances and total nitrogen and an increase in the celluloses and lignins, while other plants show no marked decrease in the rapidity of decomposition with an increase in age, due to the fact that no such marked changes take place in the composition of the plant. This was found by Bal (1) to be the case for certain plants used as green manure in

India. The first type of plant grows rapidly and with age there is a constant widening of the carbon-nitrogen ratio. In the second type of plant, the carbon-nitrogen ratio remains the same throughout the different stages of growth or changes only slowly.

These results point quite definitely to the fact that in deciding upon a plant as a source of green manure we must first of all consider its chemical composition, not in terms of its elements as C, H, O, N, etc., but in terms of definite chemical complexes. Secondly, the rapidity of the decomposition of the plant materials and the relation of the nitrogen content of the plant to that of the other plant constituents, especially the hemicelluloses and celluloses, must be given consideration. The lignins decompose much more slowly and hence will not play such an important rôle in the nitrogen transformation, although a high lignin content will delay the rapidity of cellulose decomposition, while the water-soluble substances can be used as sources of energy by nitrogen-fixing bacteria, hence their abundance will not influence considerably the nitrogen transformations, although it may in certain cases, especially in the presence of nitrate in soil.

This can be further illustrated (16) by the decomposition of alfalfa tops, more mature corn stalks, and mature oak leaves, the composition of which is given in Table 1. Sufficient moisture was added (200%) to 5-gram portions of these organic materials to make conditions aerobic and a suspension of fresh soil was used for inoculation. The $CO_2$ produced in the process of decomposition was determined and, after 28 days' incubation, the residual material was analyzed (Table 4). The corn stalks and the oak leaves received nutrients in the form of available nitrogen, phosphorus, and potassium, $(NH_4)_2HPO_4 + K_2HPO_4$.

TABLE 4.—*Decomposition of alfalfa tops, corn stalk, and oak leaves in 28 days at 25° C.*

| | Alfalfa | Corn stalks | Mature oak leaves |
|---|---|---|---|
| Water-soluble, % | 50.0 | 36.0 | 33.0 |
| Hemicelluloses, % | 43.0 | 33.0 | 55.0 |
| Celluloses, % | 74.0 | 38.0 | 72.0 |
| $CO_2$ given off, mgm | 718.0 | 870.0 | 327.0 |
| Nitrogen liberated, mgm $NH_3$ | 24.2 | —— | —— |
| Nitrogen consumed, mgm $NH_3$ | —— | 30.8 | 20.2 |

While the decomposition of the alfalfa resulted in the liberation of some of the nitrogen as ammonia in a period of four weeks, the decomposition of corn stalks and of oak leaves led to a considerable consumption of available nitrogen and its transformation into microbial cell substance.

## DISCUSSION

The two most important problems to be considered in the decomposition of green manures in the soil are the speed of liberation of nitrogen in an available form, and the amount of organic matter left in a residual form which goes to increase the soil organic matter or soil "humus." The liberation of phosphorus and other minerals will accompany or even precede the liberation of the nitrogen, while the evolution of $CO_2$ is a phenomenon definitely established which does not involve any complicated questions, except that it takes place abundantly when the soil is well aerated.

To be able to understand the nature and speed of nitrogen liberation in the decomposition of green manures (as well as of plant residues in general, as shown later, when additional nitrogen may be required to bring about active decomposition), one must consider in detail the nature and metabolism of the micro-organisms which are active in the decomposition processes. Until these problems are understood, the practice of green manures can be but a hit and miss affair. There is no wonder, therefore, that when Wollny attempted to introduce a system into the subject of decomposition of organic matter in the soil he had to prepare a text of microbiology. Unfortunately, neither the chemical composition of the plant substances nor the metabolism of the organisms were as well understood then as they are at the present time, so that his work remained only a splendid introduction to the subject under consideration.

Without going into any detailed review of the nature of the micro-organisms concerned in the decomposition of organic matter in soil and their metabolism, or the mechanism of chemical transformation of the individual plant constituents, some general principles may be laid down which will help to introduce the subject under consideration.

As pointed out above, the organic plant constituents can be broadly divided into six general groups, as follows: (a) The water-soluble substances, largely sugars, organic acids, higher alcohols, glucosides, to some extent starches, amino acids, etc; (b) the fats, oils, waxes, resins, terpenes, etc.; (c) the hemicelluloses; (d) the celluloses; (e) the lignins; and (f) the proteins. The decomposition of each of these groups by micro-organisms will involve different considerations, both in regard to the nitrogen transformation, especially the liberation of a larger or smaller part of this nitrogen in an available form, and the residual organic matter which goes to increase the amount of soil "humus."

The metabolism of an organism involves transformations of energy and synthesis of cell substance. Since most of the soil micro-organ-

isms, with the exception of the algae and autotrophic bacteria, are heterotrophic in nature, i. e., require an organic substance as a source of energy, the green manure plowed under will offer an available source of energy for the activities of a great many organisms present in the soil. It should not be assumed, however, that the plant substances making up the green manure will be attacked as a whole. On the contrary, some plant constituents will be attacked very rapidly and others only very slowly or not at all under certain conditions. The nature of the composition of a plant, therefore, will influence the nature and speed of its decomposition. Different micro-organisms are capable of attacking the various chemical complexes of the plant with a different rapidity and bring about different chemical reactions. Different soil conditions which bring about differences in the soil population, therefore, will also influence the nature of the decomposition processes.

A part of the carbon complexes will be decomposed to $CO_2$ or intermediate products (organic acids, alcohols, etc.) to yield energy for the organisms, while a part of the organic carbon will be used by the micro-organisms for the synthesis of their cell substance. The ratio between the organic matter decomposed and the amount of cell substance thus synthesized varies with the organism and with the environmental conditions. In the case of fungi, for example, as much as 30 to 50% of the carbon of the organic matter decomposed may be used for the synthesis of fungus mycelium and spores. In the case of aerobic bacteria, 20 to 40% of the carbon may thus be utilized, while in the case of anaerobic bacteria only 2 to 5% of the carbon of the organic matter decomposed is built up into bacterial cell substance. This means that if 1,000 pounds of fresh green plant material, containing 80% of moisture is decomposed completely by fungi, about 300 to 500 pounds of fungus mycelium and spores are produced, assuming that the moisture content of these is also 80% and that the carbon content of the organic matter and of the fungus cell substance is the same.

In view of the fact, however, that microbial cell substance contains a definite amount of nitrogen and phosphorus, the speed of decomposition of the organic matter will be controlled by the amount of available nitrogen and phosphorus. In the above illustration 300 to 500 pounds of moist fungus mycelium (or 60 to 100 pounds dry material) will contain 2.0 to 5.0 pounds of nitrogen. If the original organic matter can be completely decomposed and if it contains this amount of nitrogen, the process of decomposition will not be accompanied by any liberation of nitrogen in an available form. This will take place only when the fungus mycelium itself will begin to

undergo decomposition. However, the fact that plant substance is made up of a number of chemical groups, some of which will decompose more readily than others, will further complicate the problem.

The six groups of chemical complexes enumerated above will decompose in the following manner: The water-soluble constituents are decomposed most rapidly and completely. Since the nitrogen-fixing bacteria are capable of using most of these substances as sources of energy, the lack of available nitrogen will in no way limit the rapidity of their decomposition, although the presence of nitrate in the soil will stimulate the development of fungi and various bacteria which rapidly assimilate the nitrate, using the water-soluble substances as sources of energy. Since green manures may contain as much as 20 to 40% of the total dry matter in a water-soluble form, the rapidity of its decomposition, especially when $CO_2$ is used as an index, can thus be readily understood.

The second group, or the fats, waxes, tannins, etc., undergo only slow decomposition and, when they are especially abundant, as in pine needles and certain leaves, they may even interfere with the decomposition of the other plant constituents. However, they are not very abundant in the plants which are commonly used for green manuring purposes and need not influence materially the nitrogen liberation, although they may, when present in any abundance, influence the amount of the soil "humus" produced.

The hemicelluloses and celluloses may be considered together, although some of the pentosans decompose more rapidly than the celluloses and some hemicelluloses decompose less rapidly. These two groups are characterized by being free from nitrogen, by being fairly rapidly decomposed by micro-organisms, and by not being used as sources of energy for nitrogen-fixing bacteria.[4] Hence, the fungi and bacteria which decompose these two groups of plant constituents require a source of nitrogen. The more abundant these two groups are, the more nitrogen will be required. Since the hemicelluloses and celluloses may make up 60 to 65% of the mature plants and only 40% of the younger plants, their decomposition in the green manure will involve less nitrogen consumption than in the more mature plant.

The lignins form a group of plant constituents which are most resistant to decomposition. Their abundance in plant residues will even protect somewhat the celluloses against decomposition. Since the lignin content of the plant increases with age, the greater re-

[4]This is definite in the case of celluloses but still remains to be determined for hemicelluloses.

sistance of the residues of mature plants to decomposition and the larger amount of organic matter left to increase the soil "humus" becomes evident.

The proteins and their derivatives are the carriers of the nitrogen in the plant and are readily subject to decomposition. Were they free from other plant constituents, 60 to 70% of the nitrogen would become available in a few days. However, due to the presence of celluloses and hemicelluloses that are readily attacked by the soil micro-organisms, the nitrogen that becomes liberated from the decomposition of the proteins is immediately assimilated and transformed into microbial cell substance.

These facts, if carefully interpreted, make clear the phenomena observed in the decomposition of green manures, namely, the liberation of nitrogen in an available form and the amount of organic matter left which is resistant to decomposition and which goes to increase the soil organic matter or "humus."

The abundance of water-soluble constituents, the decomposition of which is independent of the amount of available nitrogen; the high protein content which leads to a rapid liberation of nitrogen, in the process of decomposition; the low hemicellulose and cellulose content which leads to a lower consumption of the nitrogen by micro-organisms; the low lignin content which helps to hasten the decomposition of the celluloses and hemicelluloses,—all of these factors lead to a rapid disintegration of green manure plants, rapid liberation of nitrogen accompanied by only partial reabsorption, and a small amount of residual material left which is resistant to decomposition.

On the other hand, in the case of mature plants and plant residues, the low content of water-soluble constituents, a high cellulose and hemicellulose content, a high lignin and low protein content lead to a slow decomposition of the plant material as a whole, slow decomposition of the hemicelluloses and celluloses, which is in addition dependent on the amount of available nitrogen, and considerable quantities of residual undecomposed material left to increase the amount of soil organic matter or "humus."

Thus the problem of decomposition of green manures, involving a knowledge of the rapidity of liberation of the nitrogen in an available form and of the amount of undecomposed or only very slowly decomposing residues which goes to increase the soil organic matter, resolves itself into a problem of the chemical composition of the plants which make up the green manure, a problem of decomposition of the various organic complexes in the plant by the different groups of soil organisms, as well as a knowledge of the metabolism of these organisms.

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# THE FERTILIZATION AND MANAGEMENT OF GRASSLANDS[1]

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Several years ago it was estimated (1)[3] that our livestock population consumed about three-fourths of the product of our improved land. In addition to that it used practically all of the product of the humid and arid grazing lands of all descriptions. Altogether, there were used for forage, 1,312 million acres out of a total of 1,903 million acres of land surface in the continental United States. Furthermore, the 231 million acres of humid grassland pastures, constituting only about one-fifth of the entire grazing area, supplied more than one-half of the forage. The significance of these figures will become more apparent when we come to consider the carrying capacity of grasslands and the relation of treatment to carrying capacity. Before we do so, however, it would be well to note certain facts that have a bearing on the utilization of pastures.

In humid regions soil type, the botanical character of the pasture plants, the intensity of grazing, and the use of lime, fertilizer, and tillage implements all serve to influence the economic returns. Beyond that, the age and species of the grazing, animals and the character of supplementary feeding, if any, also play an important rôle. Obviously, then, differences in the carrying capacity of pastures must be due to one or more of these factors. When lack of water becomes a major limiting factor, the differences in carrying capacity become more striking. Thus, the 587,000,000 acres of arid and semi-arid pasture and range can support, on the average, only one animal unit on each 24 acres (2). On the worst part of this area there is scarcely forage enough on 100 acres to support one animal unit during the grazing season. The entire area maintained, in 1920, but little more than 24,000,000 animal units, or about 22% of the livestock population in the country. As against that, the humid grassland was able to carry one animal unit on about 5 acres. Better still, the 60,000,000 acres of improved pastures in farms are able to carry one animal unit on each 2½ acres.

How much room is there for further improvement? An answer to this question may be found by an inquiry into the carrying capacity of pastures in certain European countries. Such an inquiry will show

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[3]Reference by number is to "Literature Cited," p. 27.

(3) a range of 0.91 acre per animal unit in Belgium to 2.65 acres in Great Britain and Ireland. The corresponding figure for Germany was 1.24 acres; Denmark, 1.46 acres; and the Netherlands, 1.60 acres. Since that time (1910 to 1913) there has been further improvement in some of these countries, but the ultimate possibilities are indicated by recent grassland experiments in Europe as well as in the United States. The basis for these experiments must be sought in the experience of past centuries and in the empirical practices and observations of livestock farmers in Western Europe. Toward the end of the 19th century scientific research became an important factor in the study of grassland problems. The work of Somerville is particularly notable in this connection (4). Begun in 1896, it has been continued to the present time. It has shown that basic slag alone is effective in bringing in white clover, in raising the yield and the nitrogen content of the herbage, and in increasing, to a very substantial extent, the carrying capacity of the pasture. The results of this research have found wide application and have served to swell the income of livestock farmers in Great Britain and in other European countries.

The era of cheap nitrogen, initiated within the present decade, has brought new methods of approach to the solution of livestock problems. In 1916, Warmbold began a series of fertilizer experiments on grasslands at the Hohenheim Experiment Station (5). At that time the pasture land used in the experiments was able to maintain one cow weighing 1,100 pounds on each 1.4 acres during the grazing period from the end of April to the beginning of October. There were applied, at the beginning, an equivalent of 36 pounds of phosphoric acid and 80 pounds of potash per acre. Smaller amounts of these constituents have been employed each year, as a rule in the autumn. The amounts of nitrogen used have been equivalent to 107 pounds annually. One-half of the nitrogen fertilizer has been applied as sulfate of ammonia about February 1. The other half has been given in three fractional applications in May, June, and July, mostly in the form of urea. Applications of lime at the rate of 900 pounds per acre are made once in six years.

The effect of these treatments was evident already in 1917, when 0.75 acre was sufficient for the maintenance of one cow. In the following year the corresponding area required was reduced to 0.5 acre. Perennial rye-grass is the predominant species in these pastures. Orchard grass and rough-stalked meadow grass are also prominent. Occasional plants of meadow fescue, timothy, and crested dogstail are found, while white clover is well distributed over the entire

pasture. By means of fences the pasture is divided into equal areas which are grazed alternately in accordance with a more or less definite schedule. In this manner the grass crop is utilized to best advantage and an even smooth sward maintained.

Within the last two years Nitram Limited, of London, has been carrying on extensive demonstration experiments on the fertilization of grasslands. A system of rotational grazing is employed; phosphates, potash, and lime are used as a basic dressing; and nitrogenous fertilizers are applied in successive doses in accordance with the system proposed by Warmbold. Sulfate of ammonia and nitrochalk (a mixture of ammonium nitrate and calcium carbonate) are the source of nitrogen. As to the results secured, it is stated by Page (6) that,

"Demonstrations of the system were carried out in 1927 at about 80 centres, embracing all classes of land and a wide variety of climatic and agricultural conditions. These demonstrations clearly proved that the stock-carrying capacity of pastures and their output of milk or meat, may be increased to an unprecedentedly high level. Instead of requiring 2 or even 3 acres to graze a cow or its equivalent throughout the season, the average area of intensively treated grass required for this purpose was only 0.72 acre, and in some cases figures of half an acre or less were reached. In one instance a live-weight gain of bullocks of 6¾ cwt. per acre was obtained, whilst on another farm the amount of milk produced per acre during the grazing season amounted to 710 gallons."

In order to provide for an accurate comparison of the results obtained through fertilization and other treatment of grasslands, the terms "starch-equivalent" (7) and "digestible protein" are employed. Experiments conducted by Woodman, Norman, and Bee (8) have shown that weekly cuttings gave a total yield for the season of 561 pounds of digestible protein and a starch equivalent of 1,969 pounds. Under the same conditions, fortnightly cuttings produced 679 pounds of digestible protein and a starch equivalent of 2,532 pounds. When the grass was allowed to mature and cut for hay early in June and again (as aftermath) at the beginning of October, the yield of dry matter per acre was equivalent to 6,364 pounds. When the grass was cut weekly during the period of April 3 to October 2, the total yield was equivalent to 3,796 pounds per acre. In a general way it may be stated, therefore, that weekly or fortnightly cuttings, corresponding to close grazing, will furnish only about one-half of the amount of dry matter that might be obtained when the grass is allowed to mature and is harvested for hay. On the other hand, the grass grazed, or cut at frequent intervals, contains a much higher proportion of digestible nutrients and partakes of the nature of concentrates rather than of roughage.

A careful analysis of the results mentioned by Page (5) showed that "one acre of intensively treated grass produced 2,675 pounds of starch-equivalent and 379 pounds of digestible protein." When the best nine demonstration experiments were considered, the corresponding yields were 3,887 pounds of starch equivalent and 557 pounds of digestible protein. When measured on the starch-equivalent basis, this would correspond to 2½ tons of linseed cake or to 90 bushels of wheat per acre. When measured in terms of digestible protein, it would correspond to about 1 ton of linseed cake or 100 bushels of wheat per acre. Again it should be emphasized that a high proportion of digestible protein and carbohydrates may be obtained only when lignification of the plant tissues is prevented by frequent cutting or close grazing. The relations here involved may be best shown by quoting the figures given by Page (5).

*Nutrients in young grass, linseed cake, and meadow hay.*

| Nutrients | Pasture grass (Woodman) | Linseed cake | Meadow hay |
|---|---|---|---|
| | % | % | % |
| Crude fat | 6.37 | 10.0 | 2.5 |
| Crude protein | 25.03 | 28.3 | 11.3 |
| Crude fibre | 19.89 | 11.0 | 32.5 |
| Nitrogen-free extract | 39.91 | 31.3 | 46.7 |
| Ash | 8.80 | 7.9 | 7.0 |

It is evident that young pasture grass is not unlike linseed oil meal in composition. On the other hand, mature grass made into hay contains less than half as much crude protein and much larger amounts of crude fibre. Once more it should be noted here that, under any given conditions, the age of the plant tissues determines their composition and their value for the maintenance of livestock. Moreover, numerous experiments have shown that the nitrogen content of crops may be markedly increased by the use of nitrogenous fertilizers (9). Increases equivalent to several per cent of protein may be readily secured with the aid of suitable applications of nitrogen fertilizers. Thus, mineral fertilizers, nitrogen salts, and rotation grazing or frequent cutting are fundamental factors in the new systems of grassland management (10), with the emphasis laid on the production of concentrates rather than of roughage, of digestible protein rather than of crude fibre.

Much information is now available on pasture vegetation and the influence on such vegetation of climate, soil, and systems of management. A helpful discussion of the subject has been contributed by Stapledon (11). He and others have shown that frequent cutting

tends to weaken the plants. For instance, studies at the Wisconsin Station indicate (12) that "Following two years of frequent cuttings, the productivity of a well-established bluegrass sod was reduced to less than one-fourth that of adjacent bluegrass (*Poa pratensis*) cut but once annually at maturity. Similar, but less striking results, were obtained with red-top (*Agrostis alba*)." In view of the fact that the vegetation of humid grassland pastures is made up largely of bluegrass, redtop, and white clover, the results just noted are, to say the least, quite significant (13).

Like results were obtained in a recent survey of 264 pastures in New Jersey (14). In these pastures Kentucky bluegrass, redtop, and white clover represented 37.2%, 19.2%, and 5.7%, respectively, of the entire pasture vegetation. The authors observe that, "The rotation of stock on very closely grazed pastures would seem to be more desirable than continuous grazing, since it permits the forage plants to replenish the food reserves in their roots periodically." And further, that "a surprisingly small number of New Jersey dairymen use fertilizer of any sort" on their pastures. Such of the data as are available show that untreated pastures carried stock for 140 days, while the treated pastures carried stock for 167 days. They found, likewise a higher production of milk per cow and improved grazing at the beginning and the end of the season on treated pastures. The most productive pastures yielded more than 2,000 feed units per acre and were grazed 16 days longer than the average for the state. The pastures yielding over 2,500 feed units were grazed 21 days longer than the average for the state. That still further improvement is possible is indicated by experience in England where rotation grazing combined with fertilizer treatment has in some instances lengthened the grazing season by as much as four or five weeks. Finally, it may be noted that the best pastures carried three times as many animal units as were carried on the average of all pastures.

The information developed by economic studies of pastures is quite suggestive. In Georgia, Alabama, and South Carolina pasture improvement and the development of the livestock industry have gone hand in hand (15). Studies in Virginia (16) show a carrying capacity of 4 to 5 acres of bluegrass pasture per steer. In Missouri (17) there are about 8 million acres of bluegrass pasture. These provide a grazing income of $24,000,000, an income that could be more than doubled by improved methods of management. In New York (18) "the average charge for use of pasture in 1924, was $7.83 per cow, or 13 cents per 100 pounds of milk produced. The pasture charge was only 10% as much per 100 pounds of milk as the winter

feed cost. Practically all feed for cows, however, was obtained from pasture for five months. At all times pasture is cheap compared with winter feeding." There is hardly any need for further evidence as to the magnitude of our grassland and pasture problems. Perhaps it would be sufficient to add here that the livestock population of the world, representing more than a billion and a half animals, including cattle, sheep, swine, goats, horses, mules, and asses, is an economic resource only in so far as it can be efficiently fed and maintained. The newer methods of grassland management, and particularly the use of commercial fertilizers, are intimately related to efficiency in livestock production.

Increased yields of forage and a higher carrying capacity must of necessity involve a heavier draft on the fertility of the soil. It is evident that the nature of the herbage, of the animals, and of their climatic environment will affect more or less directly the amounts of plant food removed. For our purpose bare approximations would be sufficient. Assuming forage to be the only source of food for grazing animals, we should have to allow a minimum of nutrients equivalent to 4 tons of hay. If the latter consisted of plants like Kentucky bluegrass, orchard grass, or redtop, the forage of these hays would furnish, if we are to take round figures, only something like 20 pounds of nitrogen, 10 pounds of phosphoric acid, and 40 pounds of potash per ton. Hence, the 4 tons would furnish 80, 40, and 160 pounds, respectively, of nitrogen, phosphoric acid, and potash. If legumes like alfalfa are the source of nutrients, 4 tons of the material would furnish an equivalent in round figures of 200 pounds each of nitrogen and potash and 40 pounds of phosphoric acid.

If we care to use these figures as a basis for further calculation, we should find that there is an equivalent of something like 80 million animal units in the United States.[4] The nitrogen, phosphoric acid, and potash contained in their food would correspond to something like 3.2 million tons of the first-named, about 1.6 million tons of the second, and about 6.4 million tons of the third. If the forage consisted entirely of legumes like alfalfa, the amounts removed would correspond to 8 million tons each of nitrogen and potash and about 1.6 million tons of phosphoric acid. There would also be removed large amounts of lime and sulfur and smaller amounts of other ash ingredients. However, this would not represent the entire loss to the

[4]It is usually assumed that 1 horse, mule, cow, or steer are each equivalent to 1 animal unit and that 5 hogs, 7 sheep, or 100 poultry represent a similar equivalent. Young animals are assumed to be equivalent to one-half of mature animals. It is further assumed that in semi-arid grazing regions 3 to 5 sheep rather than 7 sheep are equivalent to 1 animal unit.

soil since considerable quantities of nitrogen may be lost through leaching or through the volatilization of nitrogen compounds, or even the evolution of free nitrogen under some conditions. There would also be loss by surface washing and erosion of more or less substantial amounts of these plant food ingredients. On the other hand, some of these ingredients contained in the forage would be returned to the land in the droppings of the livestock.

What has been said here may be adequate for indicating that, as the density of the livestock population increases and the intensity of grassland fertilization and management becomes more marked, the problem of plant food replacements must become greater in scope and importance. Indeed, agricultural practice and research have taken this under consideration. We find, for instance, that legume hay acreage has increased from about 20% of the total in 1910 to about 33⅓% of the total in 1927. On the other hand, timothy and wild hay have decreased in acreage from ½ to ⅓ of the total. Together with these changes has come an increase in the acreage of tame grasses used for pastures.

There has also come the more extensive application of commercial fertilizers, even though this practice is still in its initial stages (19). We may note, further, that analytical studies have revealed very marked differences in the mineral content of uncultivated pastures in different localities. There seems to be an apparent correlation between the mineral content and feeding value of pasture grasses. There is also an apparent correlation between the carrying capacity and the health and fecundity of livestock maintained on pastures. The two mineral elements most frequently deficient are phosphorus and calcium. Conditions of malnutrition due to deficiencies of these have often been noted. References are also found in the literature to malnutrition as due now and then to deficiencies of iodine, iron, and other constituents (20). In this connection reference may be made to the work of Kelley (21) who found that small amounts of iodine used as potassium iodide increased the assimilation and retention of nitrogen and phosphorus. This was also true of the assimilation and retention of calcium, though to a less marked extent. Kelley is inclined to attribute the dietary value of cod liver oil to its iodine content.

The more intensive treatment of pastures has served to stress also the problem of pasture sanitation. Where a relatively large number of animal units is carried on any given grazing area, the pastures may become foul and the growth of the vegetation irregular. Hence, in the so-called rotation system of grazing, now being adopted in

Western Europe, harrows and other implements are used for distributing the droppings and for cutting the sod to provide better soil ventilation. Ultimately, more attention will need to be paid to methods of pasture treatment that would permit of a more or less satisfactory control of certain animal parasites and of soil-infesting insects.

Finally, it should be remembered that the use of commercial fertilizers, and particularly of relatively large quantities of nitrogen salts, will call for more effective means for dealing with the seasonal surplus of forage. Every livestock keeper must reckon with the problem of overstocking or understocking. When the pastures are flush, a larger number of animals may be carried on any given area. When the growth of the grasses is retarded, the carrying capacity is reduced accordingly. It becomes the problem of the livestock farmer to maintain the largest number of animal units that would be consistent with the supply both of summer and winter forage. It is obvious, therefore, that in periods of plenty the surplus forage must be harvested and preserved. This may be done by means of ensilaging or by means of dehydration. Accordingly, much research is now in progress in Europe, as well as in the United States, on the principles involved both in ensilaging and dehydration. In Great Britain a number of silos have already been erected for ensilaging mixtures of oats and lentils, or of other mixtures of non-legumes and legumes adapted for production in the British Isles. In the United States much information has already been accumulated, and is being accumulated, on the types of fermentation encountered in the silo and on the relation of the different types of fermentation to the conservation and loss of nutrients. No less important and interesting is the research now current on economic methods of artificial drying of forage. It is gratifying to know that the investigations on dehydration have already passed the experimental stage and that there is reason to expect the wide introduction of artificial drying as a means of conserving much valuable animal and human food in the humid sections of the United States. This is also true of some of the European countries. Finally, we should note that the information already at hand shows that artificially dried forage is of superior quality when compared with naturally dried forage. The underlying causes are not fully understood, but the research now in progress will serve to clear up our understanding of the entire problem.

## SUMMARY

1. Most of our agricultural land is used for the support of our livestock population.

2. The carrying capacity of pastures and range lands differs widely in accordance with the character of the soil, climate, herbage, and the treatment which pasture lands may receive.

3. In the United States grasslands in the humid sections will maintain an animal unit on each 5 acres. The carrying capacity of the grasslands in Western Europe is much better. On some of them an average of 1 acre is sufficient per animal unit for the entire grazing season. On the best pastures it has been shown that as many as two animal units per acre may be carried, especially where chemical fertilizers are intelligently used.

4. The expansion in the production of synthetic nitrogen fertilizers and the declining cost of these are encouraging more intensive methods of grassland management.

5. Grass, when cut young or when eaten by animals under pasture conditions, corresponds in character to concentrates, whereas grass that is allowed to mature is designated as roughage. The grass cut at weekly or fortnightly intervals will yield, under the same conditions, scarcely more than half as much as may be harvested when the grass is allowed to mature. On the other hand, the grass frequently cut or grazed is much more valuable as a source of digestible protein and carbohydrates.

6. Economic studies of grasslands and pastures are serving to emphasize their significance as an economic resource.

7. Increased yields of forage and a higher carrying capacity involve the removal of larger quantities of plant food from the soil. This emphasizes the problem of replacements.

8. The more intensive utilization of pastures calls for more careful consideration of questions of pasture sanitation.

9. The more intensive fertilization of grasslands and pastures creates the need of better provision for conserving the seasonal surplus of forage. Ensilaging and artificial drying are being investigated as a means of solving this problem.

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# PENALTIES OF LOW FOOD RESERVES IN PASTURE GRASSES[1]

L. F. GRABER[2]

Nature could not have recorded more visibly and emphatically her disapproval of our present system of permanent pasture management and our apathy and indifference to the significance of organic food reserves than she has done in Wisconsin during the past two years. In 1927, white grubs riddled thousands of acres of permanent bluegrass pastures. In 1928, an alarming outbreak of annual weeds prevailed in pastures. Both these circumstances have been largely the result of deficient supplies of reserve foods in pasture grasses. Nature's story, as the writer has observed it, in small but controlled experimental plats and in large pastures could not be more definite or dramatic. The situation, in brief, is this.

## WHITE GRUB INJURY

It may sound like a long cry from white grubs to organic food reserves in grasses, but a survey of the bluegrass region of southwestern Wisconsin has established just such a relationship. White grubs riddled acres upon acres of permanent pastures in this region during 1927 as evidenced by large areas of sod, the roots of which were completely severed from their contacts with the soil. It has been strikingly evident, however, that such insect injury was largely prevalent where the root and underground rhizome growth had been limited principally by low reserves of organic foods due to close premature grazing. Injury also occurred with deficient fertility and on soils that were thin due to outcroppings of limestone or flint.

## CONSEQUENCES OF OVER-GRAZING

The practice of continuous heavy grazing of permanent pastures maintains a vegetative growth which curtails the storage of organic foods so that productivity of the grasses is not only lessened but subterranean development of rhizomes and roots is greatly reduced. Likewise, a lack of fertility and a thin soil lower root and rhizome development. Under such conditions or combinations of such circumstances the amount of subterranean growth was so limited that the white grubs devoured practically all the roots so that the sods could be lifted from the soil like a mat from a floor. Not so, however, on the deep, fertile, and properly grazed pastures. Here only an occa-

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sional spot showed injury. Here the grubs, no doubt, consumed as much root growth as they did in the closely grazed pastures, but enough root growth remained to maintain a continuous sward of productive grass. (See Fig. 1.)

## LINE FENCE CONTRASTS

Evidence to support these conclusions is very striking. In four instances a line fence divides large fertile bluegrass pastures which are 40 or more years old. On one side of these fences the grass was for many years grazed heavily, closely, and prematurely (Fig. 2). Here the grub injury was disastrous. On the opposite sides of these fences the grass was so grazed that it had an opportunity to approach maturity and to store reserve foods in the rhizomes and roots. Here the grub injury was only slight. In other words, the closely grazed grass could not elaborate sufficient reserves to support maximum root growth, such as is needed for maximum escape from the attacks of white grubs. There is no reason to believe that the visitation of June bugs in 1926 to lay eggs which hatched into grubs was more abundant in the over-grazed grassland than that judiciously grazed. A line fence would not develop this situation, but a lack of growth in the subterranean parts on one side and not on the other would. Determinations made on samples of sods from such pastures have shown that the root and rhizome development with close over-grazing was from 35 to 50% less than the judiciously grazed grass on the opposite side of the line fence. Bluegrass and redtop grown in a greenhouse under controlled conditions for a period of two months after seeding produced from 7 to 18 times as much root growth where the plants were not clipped as where seven clippings were made during this period.

## FERTILITY AND DEPTH OF SOIL INFLUENCE GRUB INJURY

Evidence that depth of soil and fertility also have a bearing on the degree of grub injury is clearly shown by the fact that in those judiciously grazed pastures with high organic food reserves, grub injury was only serious on hillsides where the soil was thin due to outcroppings of limestone and where parts of such pasture were low in fertility due to heavy croppings many years ago, before the land was devoted to grazing. On one large pasture an example of this latter situation was most emphatic. A small but definite part of this pasture was low in fertility due to heavy cropping some 20 years ago with little or no return of manure or fertilizer before this soil was allowed to "run to grass." The grub injury on this unfertile pasture land was exceedingly severe and definite in its occurrence up to a

straight line where the fertile soil of the much older bluegrass land, that had never had heavy cropping, began. The grass on this fertile soil was practically free from grub injury. Fertility, along with

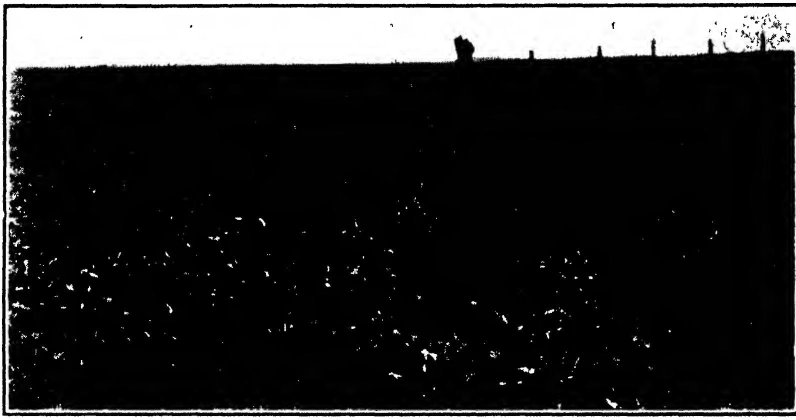

FIG. 1.—Low reserves, grub injury, and weeds from premature overgrazing. Nature "covered up her nakedness" with mulleins, ragweeds, and vervain in 1928 where white grubs had cut off over-grazed sods in 1927. Note the absence of such injury on opposite sides of the two intersecting line fences where, with high reserves resulting from the absence of close premature grazing, these pastures have escaped serious harm from white grubs and weeds. All three pastures are fertile and fully 40 years old.

FIG. 2.—A pasture contrast in August. Close premature grazing of bluegrass in May and June (left) not only lowers food reserves and weakens grasses, but eliminates the supply of pasturage during July and August when good grazing (right) is badly needed.

judicious grazing, developed a dense sod with roots sufficiently abundant so that the grass survived the grub attacks. (See Fig. 3.)

Low reserves, low fertility, and thin soil decrease the productivity of bluegrass and redtop and the amount of subterranean growth of these grasses and increase the amount of injury from white grubs.

## OVER-GRAZING A BESETTING SIN

That close, premature over-grazing is a besetting sin in the management of permanent bluegrass pastures was demonstrated dramatically and disastrously again in 1928. The appearance of dense growths of unpalatable ragweeds put an indelible stamp of disapproval on nearly every prematurely over-grazed permanent pasture. In vivid contrast to this general situation were the large pastures of cattle feeders in the bluegrass regions of southwestern Wisconsin. These were generally weed free.

FIG. 3.—Weeds, Nature's revolt against low organic food reserves. The abundant outbreak of ragweeds (right) has been due to close premature grazing in previous years, while the absence of weeds (left) is due to high food reserves resulting from the avoidance of heavy early spring grazing of the grasses. Both of these large bluegrass pastures are hilly but fertile and fully 40 years old.

The cattle grazers must manage their grasslands so as to assure a uniform supply of grass throughout the summer months. This is essential for economic gain and desired finish. In this connection a maxim of one of the oldest and most successful cattlemen in that region is of interest, *viz.*, "A steer should have as much grass to lay in as he eats." The cattle feeder cannot afford to graze closely during May and June, otherwise there would be no grazing during July and August. The avoidance of heavy premature grazing permits, for the most part, the bluegrass of the cattleman's pastures to head out or

mature. This assures storage of organic reserve foods, abundant root growth, drought resistance, a summer feed supply, the avoidance of grub injury, and the prevention of the ingress of unpalatable weeds.

## WEEDS MARK OVER-GRAZING

It is often argued that if close heavy grazing weakens grass and lowers its productivity, it should do likewise with weeds. It does. It often eradicates weeds but never unpalatable weeds. These escape grazing and persist. One of the most important of such weeds in Wisconsin is the ragweed. Most all of the bluegrass land in the southern half of Wisconsin was covered with ragweeds during the summer and fall months of 1928. Nature could not have given any more severe indictment of our faulty system of pasture management and disregard for the significance of organic reserves. "Nature covered up its nakedness," brought on by over-grazing and consequent grub injury, with weeds. But in the cattle country of southwestern Wisconsin, the fertile pastures which had not been prematurely overgrazed were very free of weed infestations.

## EXPERIMENTAL EVIDENCE

The weed growth in the experimental plats of bluegrass with reserves reduced by frequent cutting in 1927 was 10 times more abundant in August, 1928, than existed in adjacent plats where the bluegrass was high in reserve foods due to cutting only at maturity in 1927. Plats "over-grazed" with a lawn mower readily become weed infested just as do pastures over-grazed with cattle. The dominant weeds in pastures, of course, are the unpalatable ones, the ones which largely escape grazing, such as ragweeds.

Fertility helps to hinder weed encroachments in pastures. In plats where both fertility and reserves were low, the weeds were twice as abundant as they were with low reserves and high fertility. Annual weeds are notably absent in pastures where the soils are high in fertility and the grass high in organic food reserves. This is the ideal situation.

## REMEDIES FOR OVER-GRAZING

A solution of the problem of over-stocked permanent pastures lies in a much greater utilization of supplementary pasture crops. Winter rye, sweet clover, and other temporary crops will provide for early grazing until the bluegrass has headed out and stored an ample reserve of organic foods. Supplementary pastures will permit considerable fall growth of bluegrass for autumnal storage and winter protection. That such grass is more productive than that pre-

maturely over-grazed is shown in experimental trials, previously reported, where various degrees of close grazing were accomplished with a lawn mower.

Fertility, of course, is a primary essential for productivity of grasslands. No system of grazing will overcome serious deficiencies of fertility. Fertilization, no matter how accomplished, be it with seedings of legumes in pastures or with mineral and nitrogenous fertilizers, is the first step for the improvement of exhausted pasture soils, but the avoidance of early and close grazing is the first step for the improvement of grass plants which have become exhausted by improper management. Fertility leads to profitable returns from permanent pastures, but exhausted plants need consideration as well as exhausted soils.

# TECHNIC OF RICE HYBRIDIZATION IN CALIFORNIA[1]

Jenkin W. Jones[2]

## RICE HYBRIDIZATION IN OTHER COUNTRIES

The earliest record found by the writer regarding the artificial hybridization of rice dates back to 1901. In that year Hoshino (2),[3] of Japan, records having made two crosses of glutinous x common rice, one in the greenhouse of the College Botanical Garden at Sapporo, Japan, in May, 1901, and the other in a paddy field in August of the same year. He obtained 6 hybrid seeds in the greenhouse and 12 in the field. In making the crosses the glumes of the female parent (glutinous rice) were clipped off prior to emasculation and, therefore, the hybrid seeds were exposed to the air. It was not possible to tell by observation whether the hybrid seed possessed a glutinous or a common endosperm. Therefore, some of the hybrid seeds were cut and soaked in a solution of iodine. All the hybrid seeds turned violet in color as common rice does, whereas self-fertilized female glutinous seeds changed to a brown color. "It showed perfectly the phenommena of zenia in the rice endosperm." This was the first demonstration of zenia in the rice endosperm.

Koch (4) states that in 1907 Van der Stok started hybridization experiments with rice in Java. He crossed Karang Serang, an early-maturing variety of good quality, and Skrivimankotti, a high-yielding variety of poorer quality. Koch states that the best method of hybridization is as follows: Cut off the tops of the glumes with scissors a few hours before flowering (blooming), then remove the exposed anthers with a fine needle and pollinate a few hours after with pollen from the male parent. The panicles are then enclosed in a gauze envelope, which is protected at night and during rain by a little cover of dry leaves. By this method Koch, in one case, obtained 43.3% of hybrid seed. However, at times no hybrid seeds were obtained, due apparently to nonviable pollen.

In India, Hector at Dacca and Parnell at Coimbatore began hybridization work with rice about 1913.

As late as 1913 Farneti (1), of Italy, claimed that rice flowers never opened before, during, or after dehiscence of the anthers.

[1]Contribution from the Office of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture, in cooperation with the California Agricultural Experiment Station. Received for publication October 13, 1928.

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[3]Reference by number is to "Literature Cited," p. 40.

Therefore, natural crossing was impossible. All the different rice varieties present must have originated as mutations. His attempts to cross rice resulted in failures. All the flowers artificially opened, whether or not the stamens were destroyed, remained unfertilized, whereas all those flowers not operated on set seed. However, Farneti reported that it was possible to cross rice provided sufficient patience and skill were used in removing the anthers by inserting a fine instrument through the minute openings at the points of the glumes. It was difficult, however, to avoid self-fertilization or injury resulting in sterility.

Sharngapani (6) gives the following description of the method used in Bengal for crossing rice:

"The two glumes are very gently pulled apart with the fingers—no forceps should be used—and the stamens removed with a pair of fine bent forceps. About two hours later, when the rice flowers begin to open, the emasculated flowers are pollinated, and the glumes are closed and tied up with a piece of fine silken thread. The tying helps to keep the glumes in their natural position. If the glumes are not tied up, they do not close properly, and the percentage of successful crosses diminishes greatly. The tying up also does the work of bagging, and no further bagging is necessary."

Torres (7) and Rodrigo (5), in the Philippine Islands, clipped off the glumes of the female parent in the emasculation process, which was done either in the morning before blooming began, or in the afternoon after blooming had ceased. The female was pollinated the following day if emasculated in the afternoon, or on the same day when emasculated in the morning. Rodrigo reports that the average number of pollen grains per stamen in three varieties ranged from 643 to 915. This means that each floret produces from 3,858 to 5,490 pollen grains, only 1 of which is necessary for fertilization.

## RICE IMPROVEMENT WORK IN THE UNITED STATES

Rice is the most important cereal crop grown in many Asiatic countries. It is of only minor importance, however, in the United States where it has been grown since 1694. Louisiana, Arkansas, and Texas, in the order given, are the leading rice-producing states in the South, while on the Pacific Coast California grows considerable rice. In total production Louisiana ranks first and California second.

Rice improvement work in the United States consists largely of (a) the testing of varieties introduced from foreign countries, and (b) the testing of pure-line selections isolated from varieties introduced from foreign countries and from varieties grown commercially. The program to develop more desirable commercial rice varieties by hybridi-

zation was started in California in 1922 Some of the strains isolated from the first crosses made at that time are very promising.

FAULTY TECHNIC

E. L. Adams, in charge of the Biggs Rice Field Station from 1912 to 1918, attempted to hybridize rice, but no crosses were obtained.

The writer in 1920 and in 1921 tried to cross rice at the Biggs Rice Field Station, but without success. In each of these years spikelets which had emerged above the leaf sheath were carefully emasculated in the morning by gently pulling the glumes (lemma and palea) apart and removing the anthers with a pair of fine-pointed forceps. The emasculated panicles were then bagged. The following day about noon pollen was collected from panicles which were in bloom and the stigmas of the emasculated flowers were liberally dusted with this pollen. No hybrid seeds were obtained.

It seemed possible that the failure to obtain hybrid seed might be due to using bags of ordinary bond writing paper to inclose the panicles after emasculation and cross-pollination. Accordingly, in 1922, an experiment was conducted to determine the effect of using various kinds of cloth and paper bags on the setting of rice seed. This experiment indicated that the kind of bag has no appreciable effect on the number of seed set.

In the same year (1922), the time of blooming of quite a large number of flowers in different rice varieties was observed (3), and it was found that more than three-fourths of the flowers under observation bloomed between 12 noon and 2 p. m. The results of this study indicated that previous failure might have been due to nonviable pollen and that the best time to collect pollen for crossing purposes was from 12 noon to 2 p. m.

Coincident with the above observations on the time of blooming further attempts were made to obtain certain rice crosses. A large number of spikelets were emasculated by gently pulling the glumes apart and removing the anthers with a pair of fine-pointed forceps. Two hybrid seeds were obtained. One of these hybrid seeds failed to germinate in 1923, but the other produced a hybrid plant.

The conclusion was reached that the pollen collected from spikelets which were in bloom probably was not viable. In 1923, therefore, pollen was collected from anthers carefully removed from florets which were just about ready to dehisce. At this stage of development the anthers are pushed up near the apex of the glumes and are easily seen by holding the florets up to the sunlight. This pollen was placed on the stigmas of certain emasculated florets, and pollen collected from spikelets which were in bloom was placed on the

stigmas of other florets on the same panicle. In nearly all cases the pollen taken directly from the anthers before dehiscence, if sufficiently mature, resulted in fertilization, whereas the pollen collected from spikelets which were in bloom seldom produced hybrids.

It also was found, as previously observed by others, that the best practice in emasculating rice flowers is to clip off the ends of the glumes before removing the anthers, rather than gently to pull apart the glumes. The glumes (lemma and palea) are very delicate and easily injured at blooming time, and if handled are likely to dry up and result in sterility. By clipping off the lemma and palea at an angle of about 45 degrees with a small pair of scissors it has been found possible to remove the anthers very easily with little injury to the glumes or floret.

By clipping the glumes at an angle, removing the anthers with a pair of fine-pointed forceps, and using only pollen from well-developed anthers collected just before dehiscence, hybrid seed of all desired crosses have been obtained. Under field conditions, however, the percentage of seed set, even with this method, is comparatively low. On an occasional panicle 75% of the emasculated florets are fertilized, whereas on others many of the florets fail to develop. As an average, from 5 to 25% of successful fertilizations are obtained.

## IMPROVED TECHNIC

The method now used in the hybridization of rice at the Biggs Rice Field Station is as follows: Usually in the morning before the rice begins to bloom, or less often in the afternoon after the daily blooming period has passed, all except 15 to 20 spikelets are removed from the female panicle. The glumes on the remaining spikelets are clipped off at an angle of about 45 degrees. This removes about half of the upper part of the lemma, but only the end and sometimes none of the palea. By clipping the glumes in this manner all six anthers are exposed. They can be easily removed with a pair of fine-pointed forceps, often in one operation.

It is best in removing the anthers to begin with the upper spikelet proceeding in order to the lower spikelets of the panicle. With this procedure there is less likelihood of pollen falling into an open flower below. After the anthers are removed the emasculated panicles are tagged and bagged in the manner usual for cereal plants. The same day or the following day, between 12 noon and 2 p. m., the male panicles are examined and a few panicles on which the anthers are pushed well up toward the apex of the glumes are collected. The glumes of the spikelets in which the anthers are well developed are

gently pulled apart and one or more anthers are taken and placed in the emasculated female floret. It often is necessary to break the anthers open to insure that the stigmas are well covered with pollen. This can be determined with a hand lens. Often well-developed anthers will lose some pollen as soon as the glumes are pulled apart and the anthers are exposed to the air. Such anthers are ideal for use in cross-pollination and often several florets can be pollinated with a single anther in such condition. Several panicles are often required, however, to obtain sufficient pollen to pollinate 15 or 20 florets. This is owing to the fact that at any one time the anthers of only a small percentage of the spikelets are in the proper stage of development. If immature pollen is used, fertilization does not take place. After pollen has been placed on the stigmas of the emasculated florets, the panicles are again bagged and the bags are left on until the hybrid seed is mature.

It has been observed that the hybrid seed develops better within the bags than when the bags are removed after the seed starts to form. This probably is due to higher humidity within the bags, which appears to be an advantage in California, but may be a disadvantage in more humid countries.

The bags also protect the exposed seed from insects. The hybrid seeds when fully matured extend beyond the clipped glumes, and often they are considerably longer than normal seeds. The unprotected end of hybrid seeds appears to attract insects which soon destroy the entire seed if it is not protected.

Hybrid seeds often are shriveled and poorly developed and do not germinate as well as do the fully developed normally uncrossed seed However, well-developed hybrid seed germinates equally as well as uncrossed seed. Because of the poor development of some hybrid seed, very often only about 50% of hybrid seeds produce plants, even when they are started under very favorable conditions.

In Japan the improvement of rice by hybridization has been employed for many years. Japanese investigators have found that high temperatures and high humidity are favorable for fertilization in the rice plant. These factors can be controlled in a hothouse, whereas they can not be controlled under field conditions, and most of the Japanese rice crosses accordingly are made in greenhouses. The technic used by the Japanese is essentially the same as that described as now used at the Biggs Rice Field Station. Their percentage of successful crosses is doubtless higher, however, than that obtained at Biggs under field conditions.

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# EFFECTS OF DEHULLING SEED AND OF DATE OF SEEDING ON GERMINATION AND SMUT INFECTION IN OATS[1]

B. B. Bayles and F. A. Coffman[2]

## INTRODUCTION

In studies of the inheritance of resistance of oats to smut it is desirable to obtain the heaviest possible infection. Smut infection from inoculated seed in hulled oat varieties frequently is insufficient to permit a satisfactory interpretation of the inheritance of resistance. The experiments reported in this paper were conducted on the Sherman County Branch Station at Moro, Oreg., in 1925 and 1926. Their object was to study the effect of removing the hull from the oat kernel and of the date of seeding on the germination of the seed. The results of previous investigations have shown that these factors may have considerable influence on the percentage of smut-infected plants in the crop.

## REVIEW OF LITERATURE

Jensen (4),[3] working in 1887 to 1888, found that the amount of infection in oats and barley was greatly increased by dehulling the seed. Tisdale (10) showed that the infection of barley by covered smut was materially increased by dehulling the seeds. Tisdale and Tapke (11) obtained similar results with loose smut of barley. Gaines (2), Gaines (3), Stanton, Stephens, and Gaines (9), and Johnston (5) have shown that a higher degree of smut infection may be obtained in oats by dehulling the seed before inoculation.

Bartholomew and Jones (1) and Jones (6) observed that optimum temperatures for the infection of oats by loose smut (*Ustilago avenae*) were between 18° and 22° C, and that low moisture content of the soil favored infection. Reed and Faris (7) observed that low soil moisture and high temperatures were conducive to high smut infection. Johnston (5) obtained low smut infection from very early or very late seedings, and found that soil having a moisture content of but 30% or less of its moisture-holding capacity, and in which temperatures of from 62° to 66° F existed, was favorable for maximum infection. He also showed that some varieties derive part of their freedom from smut infection from the mechanical protection afforded by the glumes.

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[3]Reference by number is to "Literature Cited," p. 50.

## MATERIALS AND METHODS

In studies of smut resistance in 86 $F_3$ Markton x Scottish Chief hybrid strains grown in 1925, two adjacent rows of 40 seeds each were sown. The seed for one row was dehulled and both lots were inoculated with covered smut. No seedling counts were made, but the number of plants which matured in each row indicates that a reduction in stand occurred, due either to failure of the seed to germinate, to effects of smut inoculation, or to other causes or combination of causes. The percentage of smut infection in 1925 was so greatly increased by dehulling the seed that a more extensive study of some of the factors affecting smut infection was made in 1926.

Three varieties were grown in the 1926 experiments, namely, Markton, C. I. No. 2053, which so far has proved immune from covered smut (9), and Early Champion, C. I. No. 1623, and Sixty-Day, C. I. No. 165–1, which are smut-susceptible, as shown by Reed, Griffiths, and Briggs (8). Sowings were made on four dates. Forty rows of 20 kernels each of each variety were sown on each of the first three seeding dates. On the fourth date only 32 rows each of Sixty-Day and Early Champion, and 16 rows of Markton, were sown. Ten rows each of hulled-inoculated, hulled-uninoculated, dehulled-inoculated, and dehulled-uninoculated seed of each variety were sown on each of the first three dates. On the fourth date eight rows in each of the four groups of Sixty-Day and Early Champion and four rows in each of Markton were sown.

The seed for each row was placed in an envelope and inoculated by blackening with spores of covered smut (*Ustilago levis* (K. and S.) Magn.) The inoculum was obtained from oats grown at Aberdeen, Idaho, in 1924 and identified by V. F. Tapke, associate pathologist in smut investigations, Office of Cereal Crops and Diseases, as *U. levis* (covered smut), with a very slight mixture of *U. avenae*.

Stand counts were made about a week after the plants emerged to determine the percentage of emergence. Several methods of making smut counts have been used by different investigators. The method used may vary with the type of material being studied. In the present study the percentage of smut was determined by counting as smutted any plant with one or more smutted panicles regardless of the number of healthy panicles on the same plant.

## EXPERIMENTAL RESULTS

Data on 86 hybrid strains of Markton x Scottish Chief grown in 1925 are given in Table 1. The mean percentage of plants which

matured and the percentages of smut infection based on the plant as the unit are given for both hulled-inoculated and dehulled-inoculated seed.

A summary of data obtained in 1926 is presented in Tables 2 and 3. The data in Table 2 are averages for each of the three varieties for the four dates of seeding combined. The data given in Table 3 show the percentages of emergence and of plants matured for each of four dates of seeding of the three varieties combined. The percentage of smut-infected plants for each date of seeding, as given in Table 3, is the average of two varieties, Early Champion and Sixty-Day, as Markton was immune from covered smut.

The maximum, minimum, and mean air temperatures at Moro, Oreg., in 1926 for 5-day periods beginning with each date of seeding are given in Table 4. The average temperatures for these 5-day periods are shown graphically in Fig. 1, together with other data.

TABLE 1.—*Influence of dehulling oat kernels on percentage of plants matured and on smut infection in an $F_3$ population of Markton x Scottish Chief grown at Moro, Oreg., in 1925.*

| Treatment | Number of kernels sown per row | Mean percentage of plants matured in 86 rows | Percentage of infection in 52 strains which showed some infection |
|---|---|---|---|
| Dehulled | 40 | 37.3 | 17.1 |
| Hulled | 40 | 54.0 | 5.4 |

## EFFECT OF DEHULLING ON GERMINATION AND PERCENTAGE OF PLANTS MATURING

No seedling counts were made in 1925, but the dehulled seed of the 86 strains of Markton x Scottish Chief grown that season produced decidedly fewer plants which headed than the seed which was not dehulled. As presented in Table I, a total of 54.0% of the hulled and only 37.3% of the dehulled seed produced plants which grew to maturity.

According to the data presented in Table 2, the results obtained in 1926 were similar to those obtained in 1925. Counts were made shortly after the plants emerged to determine emergence percentages. Averages for the three varieties, Markton, Sixty-Day, and Early Champion, indicate that dehulling the seed resulted in an average reduction of 8.2% in the number of plants which emerged. The percentage emergence from dehulled seed not inoculated with smut was 5.8 less than that from seed which was not dehulled. Dehulled seed inoculated with smut showed an emergence percentage 10.6 below that of seed inoculated but not dehulled.

From the data presented in Table 2 it would appear that the seed of Early Champion was injured most and that of Markton least

TABLE 2.—*Influence of dehulling oat kernels of the Markton, Sixty-Day, and Early Champion varieties on the percentage of emergence, percentage of emerged plants which matured, and percentage of matured plants infected by covered smut at Moro, Oreg., in 1926.*

| Variety | Number of kernels sown | | Percentage of plants | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Emerged | | | Matured | | | Smut-infected | | |
| | Hulled | Dehulled | Hulled seed | Dehulled seed | Difference | Hulled seed | Dehulled seed | Difference | Hulled seed | Dehulled seed | Difference |
| Seed Uninoculated | | | | | | | | | | | |
| Markton | 680 | 660 | 78.2 | 76.2 | 2.0 | 69.3 | 63.0 | 6.3 | 0 | 0 | 0 |
| Sixty-Day | 760 | 760 | 75.3 | 71.1 | 4.2 | 63.3 | 60.8 | 2.5 | 0.2 | 3.1 | 2.9 |
| Early Champion | 760 | 760 | 77.9 | 67.2 | 10.7 | 65.5 | 55.4 | 10.1 | 2.2 | 3.3 | 1.1 |
| Total or average | 2,200 | 2,180 | 77.1 | 71.3 | 5.8 | 65.9 | 59.6 | 6.3 | 1.2 | 3.2 | 2.0 |
| Seed Inoculated | | | | | | | | | | | |
| Markton | 680 | 660 | 75.6 | 70.5 | 5.1 | 68.1 | 60.5 | 7.6 | 0 | 0 | 0 |
| Sixty-Day | 760 | 760 | 72.9 | 63.3 | 9.6 | 61.2 | 52.9 | 8.3 | 30.8 | 76.6 | 45.8 |
| Early Champion | 760 | 760 | 79.2 | 62.9 | 16.3 | 64.5 | 47.4 | 17.1 | 60.3 | 94.2 | 33.9 |
| Total or average | 2,200 | 2,180 | 75.9 | 65.3 | 10.6 | 64.4 | 53.3 | 11.1 | 45.6 | 85.4 | 39.9 |
| Summary, Inoculated and Uninoculated | | | | | | | | | | | |
| Markton | 1,360 | 1,320 | 76.9 | 73.4 | 3.5 | 68.7 | 61.8 | 6.9 | — | — | — |
| Sixty-Day | 1,520 | 1,520 | 74.1 | 67.2 | 6.9 | 62.3 | 56.9 | 5.4 | — | — | — |
| Early Champion | 1,520 | 1,520 | 78.6 | 65.1 | 13.5 | 65.0 | 51.4 | 13.6 | — | — | — |
| All Varieties and Treatments | | | | | | | | | | | |
| Total or average | 4,400 | 4,360 | 76.5 | 68.3 | 8.2 | 65.3 | 56.7 | 8.6 | — | — | — |

TABLE 3.—*Influence of dehulling oat kernels and date of seeding on percentage of emergence, percentage of emerged plants which matured, and percentage of matured plants infected with covered smut at Moro, Oreg., in 1926.*

| Date of seeding | Number of kernels sown | | Percentage of plants | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Emerged | | | Matured | | | Infected* | | |
| | Hulled | Dehulled | Hulled seed | Dehulled seed | Difference | Hulled seed | Dehulled seed | Difference | Hulled seed | Dehulled seed | Difference |
| | | | | | Seed Uninoculated | | | | | | |
| March 22 | 600 | 600 | 86.0 | 79.2 | 6.8 | 72.7 | 66.3 | 6.4 | 1.8 | 3.6 | 1 8 |
| April 5 | 600 | 600 | 82.7 | 73.0 | 9.7 | 68.0 | 57.0 | 11.0 | 0.4 | 0.5 | 0.1 |
| April 19 | 600 | 600 | 70.7 | 71.8 | 1.1 | 62.0 | 60.7 | 1.3 | 0.8 | 2.9 | 2.1 |
| May 8 | 400 | 380 | 65.0 | 55.3 | 9.7 | 58.5 | 51.3 | 7.2 | 1.8 | 6.1 | 4.3 |
| Total or mean | 2,200 | 2,180 | 77.1 | 71.3 | 5.8 | 65.9 | 59.6 | 6.3 | 1.2 | 3.3 | 1.1 |
| | | | | | Seed Inoculated | | | | | | |
| March 22 | 600 | 600 | 84.3 | 74.3 | 10.0 | 69.8 | 63.2 | 6.6 | 45.9 | 82.3 | 36.4 |
| April 5 | 600 | 600 | 78.0 | 69.2 | 8.8 | 66.7 | 52.7 | 14.0 | 47.4 | 92.8 | 45.4 |
| April 19 | 600 | 600 | 73.7 | 65.3 | 8.4 | 61.8 | 52.5 | 9.3 | 43.7 | 79.4 | 35.7 |
| May 8 | 400 | 380 | 63.5 | 45.0 | 18.5 | 56.8 | 39.7 | 17.1 | 44.1 | 88.5 | 44.4 |
| Total or mean | 2,200 | 2,180 | 75.9 | 65.3 | 10.6 | 64.4 | 53.3 | 11.1 | 45.3 | 85.8 | 40.5 |
| | | | | | Summary | | | | | | |
| March 22 | 1,200 | 1,200 | 85.2 | 76.8 | 8.4 | 71.3 | 64.8 | 6.5 | — | — | — |
| April 5 | 1,200 | 1,200 | 80.4 | 71.1 | 9.3 | 67.4 | 54.9 | 12.5 | — | — | — |
| April 19 | 1,200 | 1,200 | 72.2 | 68.6 | 3.6 | 61.9 | 56.6 | 5.3 | — | — | — |
| May 8 | 800 | 760 | 64.3 | 50.2 | 14.1 | 57.7 | 45.5 | 12.2 | — | — | — |
| Total or mean | 4,400 | 4,360 | 76.5 | 68.3 | 8.2 | 65.2 | 56.5 | 8.7 | — | — | — |

*Data computed on plant basis. Markton produced no smut; therefore data for this variety are not included in calculating the mean data on percentage of plants infected, the varieties Sixty-Day and Early Champion only being used.

TABLE 4.—*Average and daily maximum, minimum, and mean air temperatures for 5-day periods, beginning with each seeding date at Moro, Oreg., in 1926.*

| Date | Air temperature Maximum °F | Minimum °F | Mean °F | Date | Air temperature Maximum °F | Minimum °F | Mean °F |
|---|---|---|---|---|---|---|---|
| March 22 | 66 | 38 | 52 | April 19 | 63 | 42 | 53 |
| March 23 | 63 | 36 | 50 | April 20 | 60 | 37 | 48 |
| March 24 | 63 | 27 | 45 | April 21 | 60 | 38 | 49 |
| March 25 | 55 | 28 | 42 | April 22 | 57 | 39 | 48 |
| March 26 | 61 | 29 | 45 | April 23 | 62 | 29 | 46 |
| Average | 62 | 32 | 47 | Average | 60 | 37 | 48 |
| April 5 | 61 | 39 | 50 | May 8 | 59 | 31 | 45 |
| April 6 | 60 | 39 | 50 | May 9 | 65 | 31 | 48 |
| April 7 | 58 | 38 | 43 | May 10 | 72 | 36 | 54 |
| April 8 | 65 | 41 | 53 | May 11 | 79 | 40 | 60 |
| April 9 | 71 | 41 | 56 | May 12 | 81 | 46 | 64 |
| Average | 63 | 40 | 52 | Average | 71 | 37 | 54 |

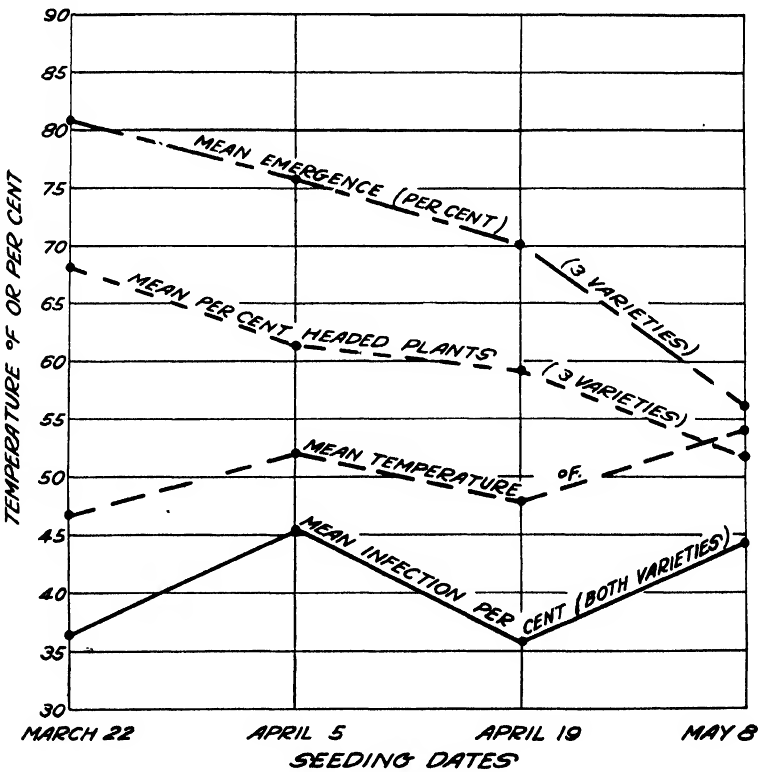


FIG. 1.—Relation between mean air temperatures at date of seeding, mean percentage of plants emerging, mean percentage of plants maturing, and mean percentage of smut infection for four dates of seeding at Moro, Oreg., 1926.

by the dehulling operation. The amount of injury resulting from dehulling possibly would depend to some extent on the plumpness of the oat kernel and other factors. Markton has longer and more plump kernels than either of the other varieties. Greater smut infection probably accounts for some of the reduction in the emergence of plants from dehulled-inoculated seed. There was a mean decrease of 5.5 in the percentage of emergence of plants from the combined hulled and dehulled seed of the two varieties, Early Champion and Sixty-Day, when the seed was inoculated. This reduction may not have been due entirely to smut infection, however, as Markton, which did not produce infected plants in these experiments, showed a decrease in emergence of 5.1% when the dehulled seed was inoculated with smut, a reduction similar to that observed in the Early Champion and Sixty-Day varieties.

The seed which was dehulled but not inoculated produced 59.6% of plants which reached maturity, while 65.9% of the hulled seed produced plants which matured. The mean percentage difference was 6.3 in favor of the seed not dehulled. Smut infection occurring independently of artificial inoculation probably decreased the percentage of plants which reached maturity. The mean percentage of plants reaching maturity when the seed was inoculated with smut was 64.4 for seed which was not dehulled and 53.3 for seed which was dehulled. This showed a reduction of 11.1% of plants reaching maturity when grown from dehulled seed.

## EFFECT OF DEHULLING THE SEED ON SMUT INFECTION

The data obtained in 1925 at Moro, Oreg., as shown in Table 1, from the cross Markton x Scottish Chief, show a marked increase in smut infection when the seed was dehulled prior to inoculation with smut. The difference in percentage of infection in the 47 $F_3$ lines of the cross which showed some infection was 11.7. The percentage of infection for the plants from hulled seed was 5.4, and for the plants from the dehulled seed it was 17.1.

The data of Table 2 show that the average smut infection obtained in 1926 from inoculated hulled and dehulled seed of the Early Champion and Sixty-Day varieties, for all seeding dates, was 45.6% from hulled seed and 85.4% from dehulled seed. There were 39.9% more smutted plants from the dehulled than from the hulled seed.

The mean percentage of infection in plants from seed dehulled prior to inoculation was 76.6 in Sixty-Day and 94.2 in Early Champion. When the seed was inoculated but not dehulled the percentage of infection was 30.8 for Sixty-Day and 60.3 for Early Champion. Dehulling the seed increased smut infection by 45.8% in Sixty-Day and

33.9% in Early Champion. In addition dehulling the seed appeared to weaken a number of the plants to such an extent that unfavorable climatic conditions and probably also the parasitic fungus destroyed them before the heading stage was reached.

From the data presented in Tables 2 and 3 it appears that the influence of smut infection on the plant often is an immediate one. In every case the emergence of plants from dehulled seed inoculated with smut was less than that from similar seed not inoculated. Smut inoculation also decreased emergence in most cases where the hulls were not removed, although the difference in emergence between inoculated and uninoculated seed was not great.

## EFFECTS OF DATE OF SEEDING ON GERMINATION AND NUMBER OF PLANTS REACHING MATURITY

Data are given in Table 3 on emergence, the percentage of plants which reached maturity, and the percentage of plants infected with smut for different dates of seeding. A mean of 81.0% of the seed sown March 22 produced plants, 75.8% of the kernels sown April 5, 70.4% of those sown April 19, and only 57.3% of those sown May 8 produced plants. A successive reduction in stand from a given number of seeds occurred as the season advanced. In all cases dehulled seed produced decidedly fewer plants than the hulled. Dehulling the seed apparently influenced germination more on the last date of seeding than on the others. Increasingly unfavorable climatic factors as the season advanced may have caused more and more of the seedlings to die before becoming established, possibly due to soil-moisture deficiency.

The number of plants which reached maturity was low, regardless of the seeding date. On the average only 60.1% of the seeds produced plants which reached maturity. The percentage was much lower for the later than for the earlier seeding dates. The reduction in the number of plants which reached maturity was comparatively uniform from date to date. A mean of 68.1% reached maturity from seed sown March 22, 61.2% for April 5, 59.3% for April 19, and only 51.6% for May 8. The differences between the percentage of plants from hulled and dehulled seed which matured was not uniform for the different dates, although in all cases plants from dehulled seed failed more often to reach maturity. Temperatures were higher on April 5 and May 8 than on the other dates, and from the seed sown on these dates a larger percentage of the plants failed to reach maturity.

Reference to Table 3 shows that the differential in the percentages of plants reaching maturity from dehulled and hulled seed was larger

for the second and fourth dates of seeding than for the first and third. On the second and fourth dates conditions appear to have favored smut infection, and, infection being more severe, proportionately more of the plants grown from dehulled seed were arrested in growth and succumbed even after emergence.

## EFFECT OF DATE OF SEEDING ON SMUT INFECTION

In these experiments soil temperatures were not taken. It has been shown (7), however, that soil temperatures 2 inches below the surface fluctuate with the daily fluctuations of the air temperatures, and it is believed that air temperatures give a fair idea of temperatures in the seedbed.

Direct correlations were obtained between the average maximum, minimum, and mean temperatures during the germination period and the amount of covered smut infection. The higher temperatures produced the higher infection percentages. This is shown graphically in Fig. 1. The data in Table 4 show that the weather was moderately cool at each date of seeding, but it was cooler for the first and third dates than for the other two. The low mean temperature prevailing at the third date of seeding apparently reduced the amount of smut infection from this seeding to a point below that for the second. The highest average maximum temperature for the 5-day period following any date of seeding was 71 degrees which occurred during the last period. While the minimum for this period was 37 degrees, the higher mean seemed to favor heavier infection of smut.

The data also indicate that the temperature at seeding time is an extremely important factor in obtaining a stand of oats at Moro, Oreg. The percentage of germination decreased as the date of seeding advanced, although the percentage of seedlings reaching maturity increased. It seems possible that the smut fungus, being more active at the higher temperatures, not only infects, but destroys weaker seedlings so quickly as to prevent emergence.

Variations in soil moisture content also probably influenced smut infection to some extent. No exactly comparable data on the moisture content of the seedbed for the different dates of seeding are available. The 1926 crop was grown in soil fallowed in 1925, which contained approximately 14% of moisture on March 25, 1926, as an average for a 6-foot depth, judging from soil samples taken on fallowed soil in other locations at the station. The moisture content of the surface 6 inches of soil would be greater than 14% on March 22, undoubtedly decreasing gradually after this date. Between March 22 and April 5, the second date of planting, a rainfall of 0.51 of an inch occurred. This rainfall came on three dates. Between April 5

and 19, the third date of planting, 0.54 of an inch of rainfall occurred. During the interval between April 19 and May 8, the last date of planting, there was 0.64 of an inch of precipitation. The percentage of germination decreased noticeably with each successive date of seeding. How much this decrease was due to the drier seedbed condition and how much to conditions more favorable for smut infection is problematical.

## SUMMARY

1. A study of the effects of dehulling the seed and of date of seeding on germination, infection by covered smut, and percentage of plants reaching maturity was made at Moro, Oreg., in 1925 and 1926.

2. Dehulling reduced germination of uninoculated seed 5.8% and of inoculated seed 10.6% in 1926.

3. When seed was dehulled but not inoculated, 6.3% of the plants failed to reach maturity as compared with 11.1% when the seed was inoculated.

4. Dehulling the seed in 1925 increased average smut infection in 47 hybrid strains of Markton x Scottish Chief from 5.4% in plants from hulled seed to 17.1% in plants from dehulled seed. Similarly, in 1926, with two susceptible varieties, Early Champion and Sixty-Day, infection increased from 45.6% in plants from hulled seed to 85.4% in plants from dehulled seed.

5. Plants from dehulled uninoculated seed of Early Champion and Sixty-Day were 3.2% smutted, and those from dehulled inoculated seed were 85.4% smutted in 1926. Plants from uninoculated hulled seed of these varieties were 1.2% smutted and those from inoculated hulled seed 45.6%. Inoculation resulted in a mean reduction of 6% in the emergence of dehulled seed and a reduction of 1.2% in hulled seed.

6. Higher germination percentages were obtained from oats sown at earlier dates of seeding.

7. A larger percentage of plants which emerged reached maturity from sowings made on the later dates.

8. The percentage of infected plants was much higher from seed sown on dates when the mean temperatures were high than when they were lower.

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# THE RELATION OF SEMINAL ROOTS IN CORN TO YIELD AND VARIOUS SEED, EAR, AND PLANT CHARACTERS[1]

P. C. MANGELSDORF AND S. F. GOODSELL[2]

## INTRODUCTION

When seeds of corn or other cereals germinate, the primary root, or radicle, is soon supplemented by a number of secondary roots arising from the radicle or hypocotyl. These structures, known as "seminal," "temporary," "seedling," or "lateral" roots, together with the radicle, constitute the root system of the young seedling during early stages of development and until the permanent root system which develops from the first and higher nodes of the stem begins to function.

Wiggans (6)[3] has shown that there is considerable variation in the average number of seminal roots per ear among different varieties of corn, as well as within the same variety. Smith and Walworth (5) have recently reported a rather high correlation between number of seminal roots per ear and yield of the progeny plants. Collins (2) has called attention to the fact that these writers have confused intra-class and inter-class correlation in computing the correlation coefficient and hence the coefficient is meaningless. Collins also pointed out that the difference ($3.6 \pm 0.63$ bushels) between two groups of 15 ears each, representing high and low numbers of seminal roots, cannot be regarded as significant unless the eight varieties involved were represented equally in both groups. Smith (4) accepts the criticism regarding the validity of the correlation coefficient. He shows, however, that the "high" and "low" groups of 15 ears each, represent fairly comparable, though not identical, distributions among the varieties. Since the varieties are not considered to be extremely diverse with respect to yielding capacity, the results of this comparison are still suggestive of a slight relationship between number of seminal roots and yield.

Although there appears to be no reason for supposing *a priori* that variations in the temporary root system of the seedlings are associated with differences in productiveness of the mature plants, the problem is one which deserves additional study, if only because of the fact that number of seminal roots is one of the few remaining ear

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[3]Reference by number is to "Literature Cited," p. 67.

or seed characters which has not been exhaustively studied in relation to yield. Also, the variation in the character is of some interest in itself from the standpoint of the morphology of the maize plant, even though it may have no relation to vigor or productiveness. In view of these facts, but more particularly because the writers happened to have on hand as a by-product from other investigations a rather large body of data which seemed to be well adapted to this purpose, the study on the relation of seminal roots to yield and various ear and plant characters was undertaken.

## NATURE OF THE DATA

In starting a project on selection in self-fertilized lines of corn in 1927, 100 ears of Surcropper, a white dent variety widely grown in Texas, were obtained from the originator, A. M. Ferguson. Mr. Ferguson stated that these ears were not selected to conform to any particular type, but were chosen so as to include as many as possible of the wide range of types occurring in this variety. Each ear was divided into six parts by shelling off two (sometimes one or three) rows of grain separately. Seed from each ear was planted in a separate ear row at each of five substations in Texas, while the sixth part was retained as remnant seed with the view of making additional selections in any ears from which promising inbred strains were obtained. The ears had been described in some detail before shelling. Progeny plants grown at each station were measured with respect to yield and other characters so that a large number of data, obtained under various soil and climatic conditions, had been recorded for each ear or its progeny. It remained only to ascertain the average number of seminal roots per ear and these data were readily obtained from the remnant seed.

The only possible objection to this procedure is that the seminal root determinations were made from seed that was slightly older, about nine months, than the seed planted in the field. This objection is more than offset by the advantage of having collected all the data before the number of seminal roots was known, and of having the ear rows distributed throughout the fields entirely at random so far as the number of seminal roots is concerned. Had the experiment been planned primarily to study the relation between seminal roots and yield, a larger number of ears should probably have been included and additional varieties might have been used. So far as this one variety is concerned, however, the experiment is probably better than had it been deliberately planned, as more data were obtained under a wider range of conditions than would have been justified had our only purpose been to discover a rather doubtful relationship between seminal roots and yield.

Throughout the discussion which follows the number of seminal roots represents the temporary roots exclusive of the radicle. Since all seeds produce a radicle, the variation in number of seminal roots is confined to the lateral or secondary seminal roots.

## PRELIMINARY STUDIES ON SEMINAL ROOTS

### SIZE OF SAMPLES

Because the supply of remnant seed of the 100 ears of Surcropper was limited and because it was desired to retain as much seed as possible, it was necessary to ascertain how small a sample would be adequate in determining the average number of seminal roots per ear. This is also important if the number of seminal roots is to be used as a basis for selection because the character obviously has little value if the minimum sample is so large that the supply of seed is exhausted or the determinations cannot readily be made on a large scale.

Random samples of various sizes drawn from a population consisting of different ears of several varieties, germinated at different temperatures, indicated that 40 seeds were adequate for this purpose under conditions of extreme variability. The coefficient of variability of this population was 35.01%. Theoretically, a population consisting of seeds from the same ear, germinated under uniform conditions, should show a lower coefficient of variability and considerably smaller samples would be required.

Random samples of various sizes drawn from a population of 270 seeds from a single ear, germinated at a constant temperature, indicate that the reduction in probable error which accompanies the increase in size of sample, conforms very closely to theoretical expectation. The probable errors, expressed as percentage of the mean, for samples of various sizes are shown in Table 1.

TABLE 1.—*Average probable errors expressed in percentage of mean numbers of seminal roots for samples of various sizes.*

| Number of seeds in sample | Number of samples | Average P.E. in percentage |
|---|---|---|
| 10 | 27 | 6.46 |
| 20 | 13 | 4.83 |
| 30 | 9 | 3.85 |
| 40 | 6 | 3.52 |
| 50 | 5 | 3.13 |
| 60 | 4 | 2.89 |
| 70 | 3 | 2.74 |
| 80 | 3 | 2.50 |
| 90 | 3 | 2.31 |
| 100 | 2 | 2.34 |

It is evident that the greatest reduction in error occurs when the sample is increased from 10 to 20 seeds. The reduction in error for samples larger than 20 seeds is scarcely sufficient to justify the additional seed, time, and labor involved. For this reason samples of 20 seeds were used in determining the number of seminal roots in the Surcropper ears and, as shown later, these proved to be adequate.

### POSITION OF SEEDS ON THE EAR

Four ears were arbitrarily divided into three approximately equal sections and the number of seminal roots was determined separately for each section. The results are shown in Table 2.

TABLE 2.—*Average numbers of seminal roots at various levels of ears.*

| Ear No. | Number of seminal roots | | |
|---|---|---|---|
| | Butt | Middle | Tip |
| 101 | 5.44 ± .12 | 4.83 ± .11 | 4.80 ± .12 |
| 102 | 4.93 ± .10 | 4.82 ± .11 | 4.55 ± .12 |
| 103 | 4.73 ± .09 | 5.01 ± .09 | 4.80 ± .13 |
| 104 | 5.43 ± .12 | 5.47 ± .12 | 4.91 ± .08 |
| Average | 5.11 ± .05 | 5.03 ± .06 | 4.77 ± .06 |

It is evident that seeds borne at the base or middle of the ear have a higher average number of seminal roots than those borne at the tip. Significant differences between the butt and middle sections are shown in one ear, between butt and tip in two ears, and between middle and tip in one ear. The averages for all ears combined show differences of 4.25 and 3.25 times the error, respectively, between butt and middle and middle and tip. These facts show clearly the necessity of using seeds from all levels of the ear in studying variation in number of seminal roots. They also indicate that the number of seminal roots is not controlled entirely by the heredity constitution of the seed, as there is no apparent reason for constant differences in heredity at different levels of the ear, except that the ovules at the tip, being pollinated later, may receive a slightly greater proportion of pollen from later-maturing plants.

### EFFECT OF TEMPERATURE

Samples from eight ears of the same variety were germinated at temperatures of 24.5°, 28°, 31.5°, 35°, and 38°C. The temperature at 38° was apparently too high as practically no germination occurred. The results at the remaining temperatures are shown in Table 3. Determinations listed under the heading "Petri dishes" were made in Petri dishes in an incubator. Those shown under "Blotters" were made between moist blotters in a standard germinating chamber.

The results leave no doubt that the number of seminal roots is

affected by the temperature in which germination occurs. Of the six possible comparisons between the means in the blotter series all but one, between 24.5° and 28°, showed significant differences. In the Petri dish series four of the six differences were significant, while two, between 28° and 31.5° and 24.5° and 35°, were not large enough to be significant.

TABLE 3.—*Effect of temperature and germinating medium on number of seminal roots.*

| | Average number of seminal roots | | | |
|---|---|---|---|---|
| | 24.5°C | | 28.0°C | |
| Ear No. | Petri dishes | Blotters | Petri dishes | Blotters |
| 106 | 4.05 | 4.57 | 4.50 | 5.04 |
| 107 | 4.28 | 3.63 | 4.45 | 3.96 |
| 108 | 4.20 | 5.20 | 5.83 | 5.61 |
| 109 | 3.63 | 4.05 | 4.91 | 3.88 |
| 110 | 4.33 | 5.02 | 5.89 | 4.62 |
| 111 | 5.41 | 5.56 | 5.75 | 5.00 |
| 112 | 3.28 | 3.60 | 4.08 | 3.28 |
| 113 | 3.75 | 3.40 | 4.27 | 3.67 |
| Average | 4.06 ± .08 | 4.45 ± .03 | 4.94 ± .11 | 4.32 ± .07 |
| | 31.5°C | | 35.0° C | |
| Ear No. | Petri dishes | Blotters | Petri dishes | Blotters |
| 106 | 5.28 | 5.00 | 2.76 | 6.37 |
| 107 | 3.93 | 4.38 | 4.17 | 4.29 |
| 108 | 4.60 | 5.92 | 3.15 | 6.85 |
| 109 | 4.53 | 5.23 | 3.36 | 5.18 |
| 110 | 4.90 | 6.48 | 5.86 | 6.55 |
| 111 | 5.87 | 6.46 | 5.13 | 6.29 |
| 112 | 4.36 | 4.00 | 3.68 | 3.83 |
| 113 | 5.13 | 4.27 | 4.18 | 4.72 |
| Average | 4.81 ± .08 | 5.22 ± .08 | 3.89 ± .09 | 5.59 ± .08 |

The averages of both series indicate that the number of seminal roots increases with the temperature to a certain point, after which a further increase in temperature is accompanied by a decrease in number of roots. Apparently, the highest average number of roots is produced at a temperature of approximately 33° to 34° C which, according to Becker (1), is also the optimum temperature for germination.

## EFFECT OF GERMINATING MEDIUM

Table 3 shows that there is a significant difference in each of the four comparisons between samples germinated in blotters and in Petri dishes. In this case the differences may well be due to moisture rather than to the medium as one series was germinated in Petri dishes in a dry oven and the other in the saturated atmosphere of a standard germinating chamber. A series of 20 comparisons be-

tween blotters and Petri dishes in the same germinator showed very little difference, the former averaging 4.78 seminal roots, the latter 4.58. Probably the germinating medium has little influence on number of seminal roots so long as other conditions remain constant.

## THE CONSTANCY OF SEMINAL ROOT NUMBER

These preliminary investigations show very convincingly that the number of seminal roots is not a definite characteristic of the seed which may be accurately determined under any set of conditions. The number of seminal roots varies with position of the seeds on the ear, with temperature, with moisture, and probably other factors such as light, oxygen, etc. Some of our data indicate that a fluctuating temperature has a different effect on number of roots than a constant one.

In spite of all of these variations, significant differences are found between ears, no matter under what conditions germination has occurred, and the relative ranking of a group of ears remains approximately the same within the limits of sampling errors under various conditions of germination. This is partially illustrated by the data in Table 3 and more forcibly by other data which it does not seem necessary to publish.

In other words, the ears of any population exhibit significant differences in average number of seminal roots which can be accurately determined if the samples are adequate and the seeds are germinated under uniform conditions.

## SEMINAL ROOTS IN SURCROPPER EARS

The average number of seminal roots of the 100 ears of Surcropper were determined from samples of 20 seeds each from each ear. The samples were taken at random from the remnant supply of seed, which represents two rows of grain from each ear. All samples were germinated simultaneously between blotters, in a standard germinating chamber, at a constant temperature of 33° C. To avoid any possible differences in moisture or temperature due to position in the germinator, the trays were rotated daily. Samples of 20 seeds each, drawn from a composite lot of seed from all strains combined, were included in each tray as a check. The means of these check samples proved to be alike within the limits of sampling error.

Of the 2,000 seeds tested, 1,922, or 96.1%, germinated and were counted for seminal roots. The average number of seminal roots per ear varied from 3.33 to 6.18, the modal number being 5.00 and the mean for the population 4.70 ± .02. The coefficients of skewness and kurtosis are 0.24 ± .24 and — 0.18 ± .49, respectively, indicat-

ing a close approximation to the normal frequency distribution. The coefficient of variability is 12.07%.

On the basis of the probable errors calculated by Denny's (3) formula, it appears that differences of 0.88 in number of seminal roots are significant for 20-kernel samples in this population. Actual comparisons of a number of ears differing by this amount show the difference to be statistically significant in each case. Obviously, there are significant differences in mean number of seminal roots between many of the ears and the variation which this population exhibits is not due alone to fluctuations in sampling.

## RELATION OF EAR AND SEED CHARACTERS TO SEMINAL ROOT NUMBER

The ears used in this study had previously been described with regard to length, diameter, shape, number of rows of grain, width of grain, length of grain, degree of denting, appearance of grain, and discoloration of the shank. As the ears could not be accurately measured for most of these characters and were merely classified into several groups, it is impossible to compute correlation coefficients from the data. If any association exists, however, it should be shown by differences in the mean number of seminal roots in the ears of contrasting groups. These differences are set forth in Table 4 which also shows the number of ears and the number of seeds included in each group.

In calculating the means and probable errors in this table, all the seeds from each group were thrown into a single population. In other words, the seeds rather than the means of the samples were treated as units, and the probable error is based on the total number of seeds rather than the number of ears in each group. This tends to reduce the size of the probable errors and to magnify the differences between means. It is justified only on the assumption that each group contains enough ears to sample the population adequately with respect to all other characters associated with number of seminal roots.

In spite of this reduction in the probable error, only three significant differences are shown. The first is a difference of 0.18 ± .059 between the means of 42 medium dented and 19 chaffy ears. This barely significant difference is contradicted by the fact that the slightly dented ears have even a lower number of seminal roots than the medium dented ears. The two other significant differences result from comparisons between ears showing no discoloration of the shank and ears showing medium or severe discoloration. These differences, though small, are 4.3 and 4.5 times their errors.

TABLE 4.—*The relation of ear characters to the average number of seminal roots.*

| Character | Class | Number of ears | Number of seeds | Average number of seminal roots |
|---|---|---|---|---|
| Length of ears | Long | 50 | 967 | 4.69 ± .030 |
| | Short | 50 | 955 | 4.69 ± .030 |
| | Difference | | | 0.00 ± .042 |
| Diameter of ears | Slender | 82 | 1,582 | 4.70 ± .023 |
| | Thick | 18 | 340 | 4.63 ± .052 |
| | Difference | | | 0.07 ± .057 |
| Shape of ears | Cylindrical | 46 | 877 | 4.70 ± .031 |
| | Tapering | 54 | 1,045 | 4.68 ± .029 |
| | Difference | | | 0.02 ± .042 |
| Number rows of grain | 10–12 | 56 | 1,072 | 4.73 ± .029 |
| | 14–16 | 44 | 850 | 4.64 ± .031 |
| | Difference | | | 0.09 ± .042 |
| Width of seed | Wide | 30 | 568 | 4.67 ± .040 |
| | Medium | 47 | 918 | 4.78 ± .031 |
| | Narrow | 23 | 436 | 4.54 ± .043 |
| | Difference: wide—narrow | | | 0.13 ± .059 |
| | Difference: medium—narrow | | | 0.24 ± .053 |
| Length of seed | Long | 33 | 642 | 4.71 ± .038 |
| | Medium | 43 | 824 | 4.69 ± .031 |
| | Short | 24 | 456 | 4.66 ± .044 |
| | Difference: long—short | | | 0.05 ± .058 |
| | Difference: medium—short | | | 0.03 ± .054 |
| Degree of denting | Slight | 39 | 752 | 4.66 ± .032 |
| | Medium | 42 | 818 | 4.76 ± .035 |
| | Chaffy | 19 | 352 | 4.58 ± .047 |
| | Difference: slight—chaffy | | | 0.08 ± .057 |
| | Difference: medium—chaffy | | | 0.18 ± .059 |
| Appearance of seed | Dull | 41 | 766 | 4.71 ± .034 |
| | Bright | 59 | 1,156 | 4.68 ± .027 |
| | Difference | | | 0.03 ± .043 |
| Specific gravity of seed | High | 50 | 938 | 4.69 ± .030 |
| | Low | 50 | 984 | 4.69 ± .030 |
| | Difference | | | 0.00 ± .042 |
| Discoloration of shank | None | 25 | 477 | 4.88 ± .045 |
| | Medium | 40 | 781 | 4.63 ± .032 |
| | Severe | 35 | 664 | 4.63 ± .036 |
| | Difference: none—severe | | | 0.25 ± .058 |
| | Difference: none—medium | | | 0.25 ± .055 |

Most of the differences shown in these comparisons are no larger than should be expected as a result of sampling errors, and even those which appear to be significant are so small as to indicate correlation of a very low order. It may be concluded, therefore, that the number of seminal roots is not associated to any appreciable degree with other seed or ear characters in this population.

## RELATION OF SEMINAL ROOTS TO YIELD

As already mentioned progeny plants from each ear were grown in separate ear rows at five localities in Texas. In some respects such a test corresponds to repeating the same experiment for five years as the variation in weather conditions at these points during 1927 was as great as the ordinary variation at any one point during a period of five years. The rainfall during the growing season ranged from 8.68 inches at Angleton to 27.48 inches at Nacogdoches, while the mean daily temperature varied from 69.13° F at Denton to 76.63° F at Beeville. The crop suffered somewhat from excessive moisture at Nacogdoches, from slight drouth at Denton, from severe drouth at Beeville and Angleton, while at College Station growing conditions were almost ideal. In addition, the five stations differ greatly in soil type so that this test appears to be fairly conclusive from the standpoint of sampling the effects of soil, moisture, and temperature.

Rows were planted 3 feet apart with a check row following each tenth ear row. Plants were thinned to approximately 3 feet apart within the row. An average of 12 plants per row, exclusive of self-pollinated plants, were harvested. Yield data are presented in terms of yield per plant and were computed by dividing the total weight of ear corn by the number of plants harvested

The yields of the check plats indicate that the fields on which these ear rows were grown were fairly uniform, except at Nacogdoches, and data used in calculating the correlation coefficient represent uncorrected yields in every case except those from Nacogdoches. The mean yields, standard deviations, coefficients of variability, and coefficients of correlation between number of seminal roots and yield are shown for each station separately and for all tests combined in Table 5.

Of the nine correlation coefficients listed in Table 5, only one, measuring the relation between seminal roots and yield at the Denton station, is statistically significant, and none are large enough to justify selection for yield on the basis of seminal root number. The coefficients of determination (Wright, 7) calculated from the lowest

TABLE 5.—*The relation between number of seminal roots and yield of 100 ear rows grown at five stations in Texas*

| Station | Average yields in pounds per plant | Standard deviation | Coefficient of variability | Correlation with number of seminal roots |
|---|---|---|---|---|
| Angleton | 0.3430 ± .0055 | 0.0815 ± .0039 | 23.76 ± 1.20 | —0.0578 ± .0672 |
| Beeville | 0.3436 ± .0069 | 0.1025 ± .0049 | 29.79 ± 1.54 | 0.0114 ± .0674 |
| College Station | 0.5422 ± .0051 | 0.0750 ± .0036 | 13.84 ± 0.67 | 0.1861 ± .0651 |
| Denton | 0.4132 ± .0033 | 0.0492 ± .0023 | 11.89 ± 0.57 | 0.2141 ± .0647 |
| Nacogdoches (actual) | 0.2916 ± .0088 | 0.1307 ± .0062 | 44.91 ± 2.54 | 0.1171 ± .0668 |
| Nacogdoches (corrected) | 0.3108 ± .0064 | 0.0942 ± .0045 | 30.29 ± 1.58 | 0.0056 ± .0678 |
| All fields | 0.3867 ± .0029 | 0.0432 ± .0030 | 11.16 ± 0.54 | 0.1512 ± .0659 |
| All fields (Nacogdoches corrected) | 0.3905 ± .0023 | 0.0346 ± .0016 | 8.87 ± 0.42 | 0.0756 ± .0670 |
| All fields (Nacogdoches omitted) | 0.4100 ± .0028 | 0.0420 ± .0020 | 10.24 ± 0.49 | 0.0870 ± .0669 |

and highest correlation coefficients show that from 0.76 to 2.29% of the variation in yield is accounted for by the variation in number of seminal roots. It may safely be concluded that the number of seminal roots is of little or no value as a criterion of yielding ability in this population under the conditions represented by this experiment.

## RELATION OF SEMINAL ROOTS TO SEEDLING VIGOR

Smith and Walworth (4) reported a positive correlation between number of seminal roots and seedling vigor, as measured by the rate of unfolding of successive leaves. Although this correlation, too, is invalid because of the method by which it was computed, it would seem that variations in seminal roots would be more likely to be associated with seedling vigor than with any other variable, as the young seedling is dependent on the temporary root system for a large part of its supply of water.

To determine whether such a correlation exists in this population, the germinated seeds of 22 of the Surcropper ears were planted in flats of soil in the greenhouse. Measurements of height were made at intervals of three or four days for a period of 17 days. The correlation between number of seminal roots and heights of seedlings at successive stages of development is shown in Table 6.

The first three coefficients and the final one are statistically significant. There also appears to be progressive decrease in the degree of correlation as the age of the plants increases and the permanent root system begins to function. This experiment, however, is open to objection on the grounds that the seedlings were transplanted soon after germination, and the correlation may be due to the fact that seedlings with higher numbers of seminal roots became established more quickly.

The test was repeated with samples of 20 seeds each from 16 ears planted directly in soil. Four successive measurements on height of plants were made with the rather surprising results shown in Table 7.

TABLE 6.—*Correlation between number of seminal roots and heights of transplanted seedlings at successive stages of development.*

| Date measured | Height in cm | S. D. | Correlation with number of seminal roots |
|---|---|---|---|
| Jan. 14 | 11.92 ± .21 | 1.47 ± .15 | 0.6252 ± .0875 |
| Jan. 18 | 21.85 ± .33 | 2.33 ± .24 | 0.4032 ± .1203 |
| Jan. 21 | 24.19 ± .38 | 2.63 ± .27 | 0.3865 ± .1223 |
| Jan. 24 | 25.54 ± .38 | 2.65 ± .27 | 0.3396 ± .1272 |
| Jan. 27 | 27.57 ± .43 | 3.00 ± .30 | 0.2832 ± .1322 |
| Jan. 21 | 33.43 ± .47 | 3.25 ± .33 | 0.4667 ± .1124 |

TABLE 7.—*Correlation between number of seminal roots and heights of non-transplanted seedlings at successive stages of development.*

| Date measured | Height in cm | S. D. | Correlation with number of seminal roots |
|---|---|---|---|
| Feb. 24 | 10.51 ± .25 | 1.50 ± .18 | —0.3477 ± .1482 |
| March 1 | 16.56 ± .34 | 1.99 ± .24 | —0.4836 ± .1292 |
| March 8 | 24.41 ± .47 | 2.82 ± .33 | —0.6214 ± .1035 |
| March 16 | 30.89 ± .73 | 4.31 ± .51 | —0.5597 ± .1159 |

In this case all four of the coefficients are negative rather than positive. Three of the values are statistically significant, and the coefficients, if they show any trend whatever, exhibit a progressive increase with age of the seedlings. The fact that in one test the seedlings were transplanted from the germinator at an early stage, while in the other the seeds were planted directly in the soil, would not seem to be sufficient to account for the marked differences in the results and it is possible that other factors are involved. It should be mentioned that neither of the lots of ears represent random samples of the population. In both cases ears were chosen which showed regular gradation in number of seminal roots from the highest to the lowest. If correlation occurred at all, this procedure would tend to magnify the size of the correlation coefficient. This does not alter the fact, however, that the correlation between seminal roots and height of transplanted seedlings is positive in each of six determinations, while in the non-transplanted seedlings it is negative in each of four determinations.

## RELATION OF SEMINAL ROOTS TO PLANT CHARACTERS

Although measurements of plant characters were made in each ear row at each of five stations, it does not seem necessary to present the data for more than one of these tests. The data from College Station have been chosen for this purpose, partly because a larger number of plants were measured and partly because the growing conditions at this station were most nearly the optimum.

The 100 ears were divided into two groups of 50 ears each, the point of separation being at the median. Ears of the "low" group ranged from 3.33 to 4.67 in number of seminal roots with an average of 4.24. Ears in the "high" group ranged from 4.68 to 6.18 with an average of 5.13. As the ear rows in these two groups were distributed entirely at random throughout the field there could be little chance for soil variation to affect the results.

Measurements to base of tassel and base of upper ear and counts of number of nodes, number of tillers, number of bent and fallen plants,

and number of smutted plants were made on 20 plants in each row. Date of silking, length of ear, and number of rows of grain were determined only for the self-pollinated plants of which there were usually 9 or 10 per row. The self-pollinated plants had been selected entirely at random, except that barren and badly smutted plants were necessarily excluded.

The results of all possible comparisons between the high and low groups with respect to these plant characters are shown in Table 8. The only significant difference occurring in these two groups is in average number of nodes, 0.21 ± .038. In these comparisons, too, the probable errors have undoubtedly been reduced by considering each plant as the unit rather than regarding the mean of each ear-row as a unit, so that the probable error is computed on the basis of approximately 500 or 1,000 individuals rather than 50. In any case the differences shown, whether truly significant or not, are so small as to indicate practically no association between number of seminal roots and characters of the progeny plants.

## EFFECT OF INBREEDING ON NUMBER OF SEMINAL ROOTS

The effect of inbreeding on the average number of seminal roots has been determined in four strains. Seed of successive selfed generations of these strains was kindly supplied by T. A. Kiesselbach, M. T. Jenkins, and D. F. Jones. The results are set forth in Table 9. The column in this table headed "O generations" represents the original open-pollinated strain in the case of the three first varieties and a first-generation single cross in the last-named variety.

The averages for all strains combined show a progressive reduction in average number of seminal roots per ear as the inbreeding is continued and the strains, theoretically, become less heterozygous. Of the 15 possible comparisons between the six averages in Table 9, 9 show significant differences. The average values for successive inbred generations exhibit a rather definite trend with the exception of the second one, which is higher, though not significantly so, than the first.

There can be no question that in these four strains a decrease in heterozygosity has been accompanied by a decrease in number of seminal roots. Whether this is due directly to the inbreeding or to changes in other characters which have been affected by inbreeding, would be difficult to determine. At any rate the association does not imply that selection, in an open-pollinated population, of ears with high numbers of seminal roots would result in sorting out the more heterozygous and hence more vigorous individuals. Other characters,

TABLE 8.—*Comparison with respect to plant characters of ears with "high" and "low" seminal root number.*

| Character measured | Seminal root class | Number of plants | Means |
|---|---|---|---|
| Days to silking | High | 448 | 73.89 ± .092 |
| | Low | 455 | 74.16 ± .088 |
| | Difference | | 0.27 ± .127 |
| Height to base of tassel in cm | High | 997 | 163.24 ± .439 |
| | Low | 997 | 161.53 ± .457 |
| | Difference | | 1.71 ± .634 |
| Height to base of ear in cm | High | 999 | 75.65 ± .343 |
| | Low | 996 | 74.48 ± .373 |
| | Difference | | 1.17 ± .507 |
| Number of nodes | High | 998 | 12.19 ± .026 |
| | Low | 997 | 11.98 ± .027 |
| | Difference | | 0.21 ± .038 |
| Percentage of plants with tillers | High | 999 | 10.80 ± .662 |
| | Low | 997 | 13.30 ± .725 |
| | Difference | | 2.50 ± .981 |
| Percentage of plants bent | High | 999 | 58.80 ±1.050 |
| | Low | 997 | 60.50 ±1.044 |
| | Difference | | 1.70 ±1.481 |
| Percentage of plants down | High | 999 | 10.10 ± .643 |
| | Low | 997 | 11.00 ± .668 |
| | Difference | | 0.90 ± .927 |
| Percentage of plants smutted | High | 999 | 0.400 ±.135 |
| | Low | 997 | 0.903 ±.202 |
| | Difference | | 0.503 ±.243 |
| Length of ears in cm | High | 440 | 17.93 ± .073 |
| | Low | 455 | 17.92 ± .077 |
| | Difference | | 0.01 ± .106 |
| Number of rows of grain | High | 443 | 13.05 ± .056 |
| | Low | 455 | 12.95 ± .052 |
| | Difference | | 0.10 ± .076 |

such as size of seed and number of tillers, are frequently affected by inbreeding and yet these characters show very little relation to yield in open-pollinated populations.

TABLE 9.—*The effect of inbreeding on the average number of seminal roots.*

| Variety | Average number of seminal roots in generations selfed | | | | | |
|---|---|---|---|---|---|---|
| | 0 | 1 | 2 | 3 | 4 | 5 |
| Hogue Yellow Dent | 4.17 ± .13 | 3.00 ± .19 | 4.61 ± .23 | 3.55 ± .20 | 3.86 ± .17 | 3.64 ± .22 |
| Hogue Yellow Dent | 4.77 ± .12 | 4.25 ± .26 | 3.48 ± .15 | 3.04 ± .15 | 2.58 ± .10 | 2.60 ± .14 |
| Reid Yellow Dent | 5.87 ± .14 | 6.31 ± .18 | 5.71 ± .17 | 5.73 ± .21 | 5.67 ± .16 | 4.21 ± .18 |
| Chester's Leaming (single cross) | 5.24 ± .11 | 5.60 ± .12 | 5.22 ± .16 | 5.31 ± .16 | 4.54 ± .12 | 5.15 ± .12 |
| Average | 5.03 ± .07 | 5.22 ± .11 | 4.81 ± .10 | 4.63 ± .11 | 4.33 ± .10 | 3.98 ± .11 |

## SUMMARY

1. The number of seminal roots varies significantly with position of the seed on the ear and with differences in temperature and moisture during germination.

2. Each ear has relatively the same average number of seminal roots under different conditions.

3. The average number of seminal roots per ear is constant within the limits of sampling error under uniform conditions of germination. Samples of 20 seeds each were found to be adequate for determining the number of seminal roots under uniform conditions.

4. Number of seminal roots proved to be independent of length, diameter, or shape of ear, number of rows of grain, and length, width, degree of denting, appearance, or specific gravity of the seed. Ears with no discoloration of the shank had a slightly higher number of seminal roots than ears with discolored shanks.

5. No correlation was found between seminal roots and yield in four tests. A barely significant correlation of 0.21 was found in a fifth test. Coefficients of determination indicate that from 0.76 to 2.29% of the variation in yield is accounted for by variation in number of seminal roots.

6. Number of seminal roots was *positively* and significantly correlated with vigor of seedlings when the seeds were germinated between blotters and transplanted to soil, but *negatively* and significantly correlated when the seeds were planted directly in soil.

7. Number of seminal roots proved to be independent of date of silking, height of plant, height of ear, number of tillers, percentage of fallen plants, and percentage of smut-infected plants. A slight association between number of seminal roots and number of nodes of the progeny plants was indicated.

8. Five generations of self-pollination in four strains resulted in a marked and progressive reduction in number of seminal roots.

9. It is concluded that number of seminal roots is of no value as a criterion for selection of productive seed ears under the conditions represented by this experiment.


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# SOIL TYPE AND POTATO YIELDS[1]

J. H. Stallings[2]

That there is a vast difference in the response of the same crops to different soil types in Florida is common knowledge. In fact, if this is not given due consideration, trucking and fruit growing in portions of the state are more or less hazardous. Knowing that this condition does exist and realizing the value of a practical working knowledge of it in connection with successful farm operations, an attempt has been made to collect as much detailed information as possible to bring out the relationship between soil type and potato yields at Penney Farms.

## EXPERIMENTAL

Eight of the most prominent soil types occurring at Penney Farms have been used in connection with this work. They are Norfolk fine sand flat phase, Norfolk fine sand, Leon fine sand loamy phase, Blanton fine sand, St. Johns loamy fine sand, Portsmouth loamy fine sand, Portsmouth fine sand, and Portsmouth fine sandy loam. These soils vary widely in their general characteristics and crop-producing power. The surface of the Norfolk fine sand, to a depth of 5 to 6 inches, is a light-gray, incoherent fine sand. The subsoil, to a depth of 36 inches or more, is a yellowish-gray to pale-yellow loose fine sand. It is deficient in humus and is considered to be very poor for general truck crops. The Norfolk fine sand, flat phase, consists of a gray to dark-gray, incoherent fine sand, underlain at about 8 to 10 inches by a yellow, pale-yellow, or grayish-yellow incoherent fine sand, extending to a depth of more than 3 feet. This type is somewhat superior to the Norfolk fine sand. The Leon fine sand, loamy phase, is a gray to dark-gray fine sand, 1 to 5 inches deep, overlying a light-gray to almost white, rather incoherent fine sand which at depths varying from 8 to 30 inches, though usually at about 15 to 22 inches, passes into a dark-brown or rusty-brown and sometimes black, dense hardpan layer. This ranges from 3 inches to 2 feet in thickness, and is underlain by a white fine sand which is always moist and compact, but when disturbed becomes incoherent and has the nature of quicksand. Blanton fine sand consists of 2 to 4 inches of a gray to dark-gray fine sand underlain by a yellowish-gray to grayish-white fine sand 25 to 40 inches thick, resting upon a very light grayish yellow to light-gray fine sand.

[1]Contribution from the J. C. Penney-Gwinn Corp., Penney Farms, Florida. Received for publication October 26, 1928.

[2]Head, Agronomy Department.

Portsmouth loamy fine sand is a very dark brown to black loamy fine sand containing a high percentage of organic matter. This dark organic material extends to 15 to 24 inches then changes to a dark-gray to gray fine sand, gradually becoming lighter with depth. Portsmouth fine sandy loam is identical with the Portsmouth loamy fine sand, except that it is slightly higher in organic matter than the latter and has a sticky gray sandy clay loam in the lower subsoil at 34 to 36 inches. Portsmouth fine sand differs mainly from Portsmouth loamy fine sand in that it has a layer of white sand from 15 to 25 inches below the surface. St. Johns loamy fine sand, to a depth of 5 to 10 inches, consists of a very dark-gray to black loamy fine sand. Below this is a light-gray to grayish-white incoherent fine sand which is underlain at depths ranging from 10 to 36 inches, but ordinarily 22 to 28 inches, by a dark-brown to black, compact, organic hardpan. The layer of hardpan, which ranges from 2 to 6 inches in thickness, rests upon a light-gray incoherent fine sand.

For convenience the two Norfolk types are grouped as Norfolk and the three Portsmouth types as Portsmouth and are treated as such in the remainder of this article.

In connection with the development of the farm operations of the J. C. Penney-Gwinn Corporation at Penney Farm, Florida, it was deemed necessary that a detailed soil survey on the scale of 2 inches to the mile be made of the entire tract and that a careful study be made of the response of all crops grown to different soil types. In keeping with this plan all data reported here were obtained from fields where the soil survey showed the soil to be uniformly of one type throughout. All acreages in connection with the potato crop were accurately chained, and a complete set of field notes kept on each field used throughout the season. All yield data represent accurately measured yields. The data were all obtained in connection with actual field operations.

Some 400 acres or more were planted to potatoes between January 20 and February 10, 1927, on the leading soil types mentioned above for the spring crop. Uniform fertilizer treatment and cultural practices were used on the entire acreage, thus making it possible to obtain comprehensive data bearing on the relation of soil type to potato production during the season.

TABLE 1.—*Relation of soil type to potato yield in the spring of 1927.*

| Soil type | Yield on percentage basis |
|---|---|
| Norfolk | 100 |
| Leon fine sand, loamy phase | 170 |
| Blanton fine sand | 171 |
| St. Johns loamy fine sand | 224 |
| Portsmouth | 264 |

The data contained in Table 1 were obtained by taking the average acre yield of No. 1 potatoes for a few of the representative fields located on Norfolk soil as 100% and similar averages for each of the other soil types and expressing these in per cent, using the average yield of Norfolk as 100%. An examination of the data clearly reveals a decided relationship between soil type and potato production with the spring crop. The heavier St. Johns and Portsmouth soils proved to be far superior to the lighter, drier Norfolk, Leon fine sand loamy phase, and Blanton soils.

The Norfolk soils made the poorest showing of all the types used. They proved to be very unsatisfactory for potatoes in every case. This is largely because of their lack of humus, their open, sandy character, and their inability to retain moisture during the growing season.

The Blanton fine sandy soil, which is somewhat heavier, slightly more compact, and less droughty than the Norfolk soils, proved to be a superior potato soil to the latter. This soil, however, did not rate as a first-class potato soil, as may readily be seen. It, too, is poor at retaining moisture.

The loamy phase of Leon fine sand proved to be only a medium potato-producing soil. Due to the peculiar nature of this soil, it, too, has a tendency to be droughty or very poor at retaining moisture.

The St. Johns loamy fine sand, which is a much heavier and more compact soil than either of the above, was superior to them in producing potatoes. The high organic matter content, its compact nature, and its natural low position make it very efficient at holding moisture which accounts in part for its superiority as a potato soil.

The Portsmouth soils easily proved their superiority for potato production over all the other soil types during this period. This is largely because of their larger humus content, more compact nature, and ability to retain moisture during drought.

Potatoes were planted on the same types of soil during the fall of 1927, but on a much smaller acreage, with the results listed in Table 2.

TABLE 2.—*Relation of soil type to potato yield in the fall of 1927.*

| Soil type | Yield expressed on percentage basis |
|---|---|
| Norfolk | 100 |
| Leon fine sand, loamy phase | 140 |
| Blanton fine sand | 155 |
| St. Johns loamy fine sand | 305 |
| Portsmouth | 321 |

The figures in Table 2 were obtained by taking the average total acre yield of graded potatoes for all the Norfolk acreage planted as

100% and similar averages for each of the other soil types and expressing these in per cent, using the average acre yield of Norfolk as 100%.

The percentage figures for the various soil types of the fall crop are not exactly the same as the corresponding figures for the spring crop, to be sure, but there is indeed a very close correlation between them. In every instance, the various soil types for the fall crop maintained the same positions in the scale of relative values as for the spring crop. This shows conclusively that there was a decided relationship between soil type and potato production during the spring and fall of 1927.

The results reported above were obtained during seasons when the rainfall was about the average or normal for this section. Since the moisture factor is often the limiting or controlling factor in potato production on these soils, it is natural to expect those soils of low water-holding capacity to suffer more severely than those capable of retaining large quantities of moisture during normal or dry seasons. However, with the moisture factor satisfactorily solved, either by means of an adequate amount of rainfall properly distributed through the growing season or by irrigation, this relationship will be much less noticeable. On the other hand, should there be a surplus rainfall the heavy soils, having a natural low position and an extremely high water-holding capacity, will be much more easily affected adversely than the lighter and more porous ones. This is clearly borne out by the data given in Table 3 which were obtained from the 1928 spring potato crop.

TABLE 3.—*Soil type and potato yields for the spring of 1928.*

| Soil type | Number of acres planted | Total yield in barrels | Average acre yield in barrels | Yield expressed on percentage basis |
|---|---|---|---|---|
| Norfolk fine sand, flat phase | 16.10 | 919 | 57.0 | 100 |
| Leon fine sand, loamy phase | 11.20 | 566 | 50.5 | 89 |
| Blanton fine sand | 80.05 | 5,091 | 63.7 | 112 |
| St. Johns loamy fine sand | 5.00 | 293 | 58.6 | 103 |
| Portsmouth | 132.20 | 8,534 | 64.5 | 113 |

In preparing the data in Table 3, only the results from those fields where the soil was uniformly of one type were used. There is a wide variation in the total acreages listed for the different soil types which naturally will affect the final results to some extent, but which will enable one to get some idea of the differences in the response of some

of the soil types to potato production during the spring of 1928 as compared with that of the spring and fall of 1927.

It is indeed interesting to note that the Norfolk and Blanton soils compared very favorably with the Portsmouth and St. Johns loamy fine sand soils as potato soils during this season and were superior to Leon fine sand, loamy phase. On first thought it appears difficult

TABLE 4.—*Average monthly rainfall from 1876 to 1926.*

| | |
|---|---|
| Jan. 2.75 | July 6.50 |
| Feb. 3.75 | Aug. 6.30 |
| March 3.90 | Sept. 5.30 |
| April 3.30 | Oct. 3.75 |
| May 5.00 | Nov. 1.90 |
| June 6.75 | Dec. 360 |

TABLE 5.—*Daily rainfall in inches for first six months of 1928.*

| Day | January | February | March | April | May | June |
|---|---|---|---|---|---|---|
| 1 | 0.08 | | | | | |
| 2 | | | | | | |
| 3 | | | | | | |
| 4 | | | | | | 0.25 |
| 5 | | | | | | |
| 6 | | | | | | |
| 7 | | | | | 0.95 | 0.06 |
| 8 | | | | | 0.08 | |
| 9 | 0.07 | | | | | |
| 10 | | | | 1.40 | | 1.15 |
| 11 | | | 0.52 | 0.91 | | |
| 12 | | | | | | |
| 13 | | 0.42 | | | 0.05 | |
| 14 | | | | | | 0.80 |
| 15 | | | | 3.60 | | 2.50 |
| 16 | | 0.33 | 0.06 | | | 1.40 |
| 17 | | | 0.70 | | | |
| 18 | | 0.47 | 0.07 | | | |
| 19 | | | | | | |
| 20 | 0.04 | | | | | |
| 21 | | | | | 0.19 | 0.20 |
| 22 | 0.22 | | | 0.60 | 0.40 | 0.90 |
| 23 | | 0.04 | | 1.25 | 0.84 | 0.22 |
| 24 | | 1.50 | | | | 0.20 |
| 25 | | 0.12 | 0.20 | | | 0.85 |
| 26 | | | 1.20 | | | 0.25 |
| 27 | 0 30 | | 0.10 | 2.30 | | |
| 28 | | | | | | 0.40 |
| 29 | | | | | | |
| 30 | | | 0.12 | | 1.65 | |
| 31 | | | | | 0.25 | |
| Total | 0.71 | 2.88 | 2.97 | 10.06 | 4.41 | 9.18 |

to explain this peculiarity in the light of the results reported in Tables 1 and 2. However, an examination of the rainfall data in Tables 4 and 5 will reveal the proper explanation.

Table 4 shows the average monthly rainfall for this area from 1876 to 1926. The average rainfall for January, February, March, and April, the spring potato season, is very light. The same is true for October, November, and December, the fall potato season. The rainfall for 1927 was about average.

The figures in Table 5, however, reveal a different situation. The rainfall during the spring potato season of 1928 was much above the average.

In view of the fact that the inability of the lighter soils to retain sufficient moisture for maximum potato production during an average season is responsible in large measure for their inferiority as potato soils, the above rainfall data reveal a very satisfactory explanation for the peculiar reversal of form of some of the soil types to potato production during the spring of 1928 over the spring and fall of 1927.

Beginning with the last week in January, the rainfall for the most part was about as near ideal for potato growing as could be expected until the latter half of April when the unprecedented sum of 10.06 inches fell from Arpil 10 to 27, inclusive. Until the heavy rainfall during the last half of April the potatoes on the Portsmouth and St. Johns soils had a decided lead on those on the lighter, drier types of soil, but even at that the potatoes were doing well on the latter types because of the very favorable rainfall distribution. However, it was during the period of heavy rains in April that the potatoes on the heavy Portsmouth and St. Johns soils suffered severely from excessive rainfall, while at the same time the Blanton and Norfolk soils were in excellent condition for optimum potato production. Satisfactory drainage was much more difficult to obtain on the St. Johns than on the Portsmouth soils during this period. However, potatoes on both types suffered severely in places. The high water-holding capacity of the St. Johns soil, together with its natural low position, made it next to impossible to drain it sufficiently during the heavy rains in April to prevent considerable damage to the crop. During this same period the potatoes on the Blanton and Norfolk soils were being very highly favored by an adequate water supply.

However, in spite of the serious handicap placed on the Portsmouth and St. Johns soils by the heavy rainfall in April, the Portsmouth still maintained its lead as a potato-producing soil with St. Johns following only slightly behind Blanton, which in turn rated very close to Portsmouth during this season.

The Norfolk soil made a very creditable showing during this period also. In addition to being favored with a satisfactory rainfall distribution, this soil had another decided advantage over the two previous seasons because of the fact that nothing but the flat phase of Norfolk fine sand was planted to potatoes this season, whereas during the two previous seasons considerable Norfolk fine sand was planted. The Norfolk fine sand is much inferior to the flat phase of Norfolk fine sand as a potato-producing soil; and tends to lower the average yield. The flat phase of Norfolk fine sand normally rates very close to Blanton fine sand as a potato soil.

The average acre yields of the Leon fine sand, loamy phase, soil was somewhat below that of Norfolk fine sand, flat phase, and Blanton fine sand during this season. This is due largely to the fact that areas of the former contain pockets of hardpan which prevent water passing through the subsoil fast enough to prevent the plants from being seriously damaged by excessive water during periods of excessive rainfall.

## SUMMARY

The data reported show that there was a marked relationship between soil type and potato yields for the spring and fall of 1927. The Portsmouth and St. Johns soils proved to be far superior potato-producing soils during this period than either the Norfolk, Leon fine sand, or Blanton types.

The extremely heavy rainfall during the last half of April, 1928, favored the more droughty Norfolk and Blanton soils more than the heavier Portsmouth and St. Johns. Areas of potatoes on the last two types were severely damaged by the excessive rains in April. Notwithstanding this handicap, the Portsmouth soil was the heaviest producer of all the types used, even during this wet season.

The low elevation and consequent poor drainage of the St. Johns caused it to suffer more severely during the period of heavy rains in April than the other types used. The characteristic hardpan pockets in the Leon fine sand, loamy phase, caused the potatoes to suffer materially from excessive moisture during the period of excessive rainfall which resulted in low yields. The potatoes in the open porous Norfolk and Blanton soils received practically no damage during the period of heavy rainfall, consequently, they were really benefited by the excessive rains, while those on the other types were severely handicapped.

# EFFECT OF SOME SEED POTATO TREATMENTS ON GERMINATION AND YIELD[1]

J. H. STALLINGS[2]

Much has been said from time to time about the proper method of handling seed potatoes before planting in order to obtain maximum yields of good quality potatoes. Some experimental work has been conducted to determine the effect of various seed treatments upon the germination of the seed piece, but little effort has been made to follow through to harvest the influence of the various seed treatments used upon the yield and quality of the potatoes produced from such treatments. The aim of most investigators thus far has been to discover those practices which lead to high germination of the seed piece which in turn result in good stands. Apparently, they have assumed that the best yields would naturally follow the best stands.

Observations made during the spring of 1927 indicated very clearly that better stands were obtained from planting seed pieces which had been allowed to stand from 24 to 48 hours after being cut before planting than from planting freshly cut seed pieces. It was also clearly evident that seed pieces which had been dusted with sulfur did not produce good stands, while, on the other hand, dusting with lime seemed to have a neutral or slightly beneficial effect upon germination.

It is generally conceded that one of the first essentials for successful potato growing is the getting of a good stand of potatoes. However, certain observations made in connection with the 1927 potato crop led the writer to question whether or not the treatments which resulted in low or high stands would necessarily result in low or high yields of quality potatoes.

With these points in mind an experiment was planned for the spring of 1928 for the purpose of determining not only the effects of different treatments of the seed piece on the resulting stand of potatoes but upon the yield and quality of potatoes as well. Because of the fact that it is more difficult to obtain satisfactory stands of potatoes on the lighter, drier soils than on heavier, wetter ones, the experiment was carried out on Norfolk fine sand.

An area of Norfolk fine sand, 70 feet by 210 feet, was divided into 10 blocks equal in size and planted to potatoes. The potatoes of each

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block received the treatment indicated in Table 1 before being planted. The fertilizer and cultural treatments were uniform for all blocks throughout the season.

TABLE 1.—*Plan of experiment.*

| Block No. | Treatment |
|---|---|
| 1 | Planted immediately after being cut |
| 2 | Planted 24 hours after being cut |
| 3 | Planted 48 hours after being cut |
| 4 | Planted 72 hours after being cut |
| 5 | Planted 96 hours after being cut |
| 6 | Dusted with sulfur |
| 7 | Dusted with lime |
| 8 | Dusted with manganese sulfate |
| 9 | Dusted with manganese |
| 10 | Dusted with copper sulfate |

The potatoes were planted February 8, the germination count made March 14, and the crop was harvested May 4. Each block should have had 402 plants for a 100% stand. The number of plants found in each block, together with the accompanying yield, is given in Table 2.

TABLE 2.—*Effect of some seed potato treatments on germination and yield of potatoes.*

| Block No. | Treatment | Number of plants | Yield in bushels |
|---|---|---|---|
| 1 | Planted immediately after being cut | 248 | 3 |
| 2 | Planted 24 hours after being cut | 305 | 3 |
| 3 | Planted 48 hours after being cut | 313 | 2¼ |
| 4 | Planted 2 hours after being cut | 339 | 2½ |
| 5 | Planted 96 hours after being cut | 295 | 1¾ |
| 6 | Dusted with sulfur | 307 | 2½ |
| 7 | Dusted with lime | 339 | 3 |
| 8 | Dusted with manganese sulfate | None | 0 |
| 9 | Dusted with manganese | 289 | 2¾ |
| 10 | Dusted with copper sulfate | None | 0 |

An examination of the figures in Table 2 will show that the smallest number of plants obtained on any one block, except blocks Nos. 8 and 10, the seed pieces of which were dusted with manganese sulfate and copper sulfate, respectively, and on which there were no plants, was obtained on block No. 1. The potatoes on this block were planted immediately after being cut. There was a progressive increase in the number of plants obtained on blocks Nos. 1 to 4, inclusive. This tends to indicate a more or less direct relation between germination and the length of time the potatoes are held after being cut before planting. The increase in germination increases

directly with the length of time the potatoes are kept out of the ground from the time they are cut to the 72-hour period, the maximum stand being obtained with this group. There was a decided decrease in germination, however, when the cut potatoes were held over 96 hours, as shown by block No. 5.

Dusting with sulfur gave 307 plants which is somewhat below the figures for blocks Nos. 3 and 4 on which the seed potatoes were held out of the ground 48 and 72 hours, respectively, after being cut. Those dusted with lime produced 339 plants which is equal to the number of plants obtained on block No 4. Blocks Nos. 8 and 10, the potatoes of which were dusted with manganese sulfate and copper sulfate, respectively, produced no plants, thus showing that dusting with these materials destroyed the germinating power of the seed.

The effects of the various treatments were not as noticeable on the stand as indicated by the number of plants obtained on the different blocks as upon the uniformity of germination and growth of the potatoes. The plants in block Nos. 2 and 3 germinated and grew much more uniformly at first than those in block No. 1. Block No. 4 had a larger number of plants than either of the three blocks previously mentioned, but had less uniformity of germination and growth than either blocks Nos 2 or 3. The plants of block No. 5 were decidedly weak and those in block No. 6 very irregular in both germination and growth. Block No. 7 contained the same number of plants as block No. 4, but the plants in the former were more uniform in germination and growth than those in the latter. Dusting with manganese sulfate and copper sulfate killed the seed completely, while those dusted with manganese produced 289 plants out of a possible 402, all of which were decidedly weak from the start.

A comparison of the yield data with that for germination brings out some very interesting facts in so far as this particular experiment is concerned. There seems to be very little uniformity between the early germination and growth of potatoes and the actual yield and quality of the potatoes produced which is surprising. For example, the highest yield and easily the best quality of potatoes, were obtained from those potatoes planted immediately after being cut. It is true that blocks Nos. 2 and 7 produced the same yield as block No. 1, but the quality of the potatoes from the latter was far superior to that of the other two blocks. Block No. 1 had only 248 plants as against 305 and 339, respectively, for blocks Nos. 2 and 7. The germination and early growth with block No. 1 was much less satisfactory than with blocks Nos. 2 and 7, but the yield was the same

and the quality was superior. There were decidedly more No. 1 potatoes in block No. 1 than in any other block in the test.

The yields of blocks Nos. 3, 4, and 5, where the potatoes were planted 48, 72, and 96 hours, respectively, after being cut, were lower, and the potatoes inferior in quality to those of the three blocks mentioned above. This would indicate that in so far as this experiment is concerned it was not advisable to cut the potatoes very far in advance of the actual planting date. Those planted after being cut 96 hours produced the lowest yield and poorest quality of potatoes of all the treatments, except that of blocks Nos. 8 and 10 where the yields were zero.

It is also interesting to note that notwithstanding the fact that the potatoes dusted with manganese made a much poorer showing at the start than those planted 48 hours after being cut, the former actually produced a larger yield and a better quality of potatoes than the latter. Evidently, the first influence of manganese was one of retardation but later became a stimulating one.

It is only natural that the question should be raised as to why block No. 1 with 248 plants, the smallest number of plants in any one block, should produce better potatoes than all the other blocks, and actually more in all except two instances.

Were no other data available than that reported above, the assumption might be made that the moisture content of the soil was the limiting factor of production and that 248 plants, the number in this area, were able to utilize the moisture more economically than a larger number of plants on equal areas and also that a shock of some sort might have resulted from the various treatments before planting. However, considerable data at hand not reported here tend to explode this theory.

Until more data are available it will suffice to say that these results tend to indicate that in so far as this particular experiment is concerned the early advantages gained by the treatments were only temporary and were actually overtaken during the growing season by potatoes produced from seed pieces planted immediately after being cut.

# PROLIFERATION IN *POA BULBOSA*[1]

P. B. KENNEDY[2]

The terms "proliferation" and "vivipary" are considered in most botanical literature as synonomous. However, Crozier (1)[3] describes viviparous as "producing bulbs or seeds which germinate while still attached to the parent plant," and proliferous as

"developing buds, branches, flowers, etc., from unusual places. Applied, for example, to a flower from which another flower or a branch proceeds, to a leaf from which other leaves or branches arise, to a bulbous plant which abnormally produces bulbs upon the stem above ground, or to any plant which forms young plants in unusual number about its base."

*Poa bulbosa* is a grass which normally produces bulbs at the base, and abnormally produces bulbils in the inflorescence. Therefore, according to the definition, this grass is a proliferous form of *Poa bulbosa* and not a viviparous grass, as it is frequently termed in the literature, namely, *Poa bulbosa* var. *vivipara*.

Ward (5), referring to a related species, *Poa alpina*, says, "It is rare in England and is interesting as it becomes viviparous in alpine situations." He states also that some forms of *Festuca ovina* are viviparous, and that *Poa laxa* var. *stricta* occurs only in the viviparous state.

Sowerby (6), referring to *Poa bulbosa*, states, "On the continent it is often viviparous but has not been observed in this condition in Britain." Bews (12) mentions that "in abnormally wet years, some of our South African grasses show abnormal vivipary, e.g., *Eragrostis brizoides*."

Many such citations have been noted, all using the term vivipary inaccurately for proliferation.

The truest form of vivipary in plants is described and illustrated by Schimper (2) and is that in which the seeds of certain mangrove plants germinate without a period of rest, while still attached to the tree. A hypocotyl is produced which attains a length of 60 cm before falling. The fused cotyledons are left on the tree, having served their function as absorbing organs.

Guppy (3) corroborates the statements of Schimper concerning vivipary in mangroves and cites numerous examples of partial or

[1]Contribution from the Division of Agronomy, College of Agriculture, University of California, Berkeley, California. Received for publication November 3, 1928.

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[3]Reference by number is to "Literature Cited," p. 90

complete vivipary in many other plants. In all instances he uses the term vivipary in association with fruits, seeds, and embryos only.

Proliferation, or prolification, is not uncommon in many genera of grasses, such as *Lolium*, *Festuca*, *Dactylis*, *Eragrostis*, *Elymus*, *Poa*, etc.; but, until recently, this teratological phenomenon has never been considered as having commercial possibilities. No satisfactory explanation seems to be given as to what causes plants to proliferate, nor is there any experimental evidence that anyone has produced proliferation in plants. It is thought to be associated with high altitudes and seasons of high rainfall, but when once the apogamous condition has become fixed it seems to have little regard for either altitude or rainfall. Some specimens of completely proliferated *Poa bulbosa* were obtained at a low altitude (about 300 feet) under the conditions of extreme heat of the interior valley of California but on irrigated areas.

*Poa bulbosa* is indigenous to and widely distributed in Europe, extending to Asia and Africa. Boissier (4) and Ward (5) list it under maritime grasses of waste places in southeast England. Sowerby (6) mentions its occurrence on sand and fine shingle on the seashore along the southern and eastern coast of England. Bentham and Hooker (7) cite it as

"in dry places, on roadsides; especially near the sea, in temperate and southern Europe, and across Russian Asia, extending northwards into southern Scandinavia. In Britain, chiefly near the sea, and only in the southern and eastern counties of England."

Rouy (8) states that it occurs all over France, extending to other parts of Europe, western and Central Asia, and to Africa. These references to its occurrence in Asia are confirmed by Korovin (14) who describes it as the dominant vegetation over extensive areas in Turkestan where it occupies 50% of the vegetation of the deserts and foothills with an annual rainfall of about 10 inches. Vilmorin (9) mentions it as a perennial of northern Europe, abundant in shady and gravelly places near the coast, stating that it is of little interest from a forage point of view. He notes the existence of a viviparous form. Hein (10) gives its occurrence in sunny dry places in the mountains of north and central Germany.

Vinall and Westover (13) report that *Poa bulbosa* was grown in the Arlington Experimental Grass Garden, Washington, D. C., in 1907, 1908, and 1909, and at Pullman, Washington, in 1907. At that time its commercial possibilities were not recognized. It is not mentioned or listed in the voluminous literature on grasses by such well-known agrostologists as Vasey, Scribner, Beal, and Piper, and

only a mere mention of it is given in Hitchcock's *Text Book of Grasses* with no reference to its occurrence in the United States.

Nothing more was heard of *Poa bulbosa* until 1915 when it was found established in the lawn of the Capitol Square at Richmond, Virginia. Some of the dry bulbs were transferred to the Forage Crops Office of the United States Department of Agriculture and planted in the Arlington Turf Garden, Washington, D. C. According to Lyman Carrier (formerly of the U. S. Department of Agriculture) of Coquille, Oregon, these bulbs grew satisfactorily and the grass was positively identified by him as *Poa bulbosa* in 1916.

Westover and Fitts (11) and Vinall and Westover (13) give excellent accounts of their experiments with *Poa bulbosa* at the Arlington Turf Garden and recommend its use as a green turf for lawns which turn brown in winter, especially Bermuda-grass lawns. The bulbils are scratched into the sod and, as they grow only in winter, they produce a green growth when the Bermuda grass is brown, remaining dormant during the summer when the Bermuda grass is flourishing They recommend its use for lawns and fairways but not for putting-greens, as it does not endure close cutting satisfactorily. Bulbils are now being produced on a commercial scale in Oregon.

Just how the grass was introduced into Oregon does not seem to be known with certainty, although it is thought that the first bulbils were brought from Chile by Mrs. Elinor Hanley Bush of Medford, Oregon. It seems certain that the grass spread from, rather than to, the Bush ranch where it is now abundant. However, this does not explain its presence in California in 1919. The author is inclined to believe that it is associated with the introduction of alfalfa seed either from Europe or South America.

Field acquaintance with the proliferous form of *Poa bulbosa* began in April, 1919, when, with B. A. Madson, it was discovered along the margin of a 5-acre field of alfalfa 3 miles from Escalon, San Joaquin County, California, at an elevation of about 300 feet. The alfalfa was irrigated and presented a bright green spot in a landscape otherwise brown from dry natural pasturage and ripening grain. The grass made a dense growth along the margin of the farm roadway and extended into the alfalfa in an irregular manner to a distance of about 20 feet. It was from 12 to 16 inches tall. All of the panicles were completely proliferated and not a single normal spikelet could be detected. None of the plants were producing true seeds and the distribution was not general throughout the field.

In June, 1925, F. C. Reimer, Superintendent of the Southern Oregon Branch Experiment Station, called attention to the occur-

rence of the grass in considerable quantities 5 miles east of Medford, Jackson County, Oregon, at an elevation of about 1,400 feet. Mr. Reimer's letter of April 26, 1926, states,

"It first made its appearance in a field near here about four or five years ago. It has multiplied rapidly in a very large pasture and seems to be a very aggressive grass. The owners of this and adjacent pastures are highly enthusiastic over this grass due to its aggressiveness and the fact that cattle are extremely partial to it and fatten on it very readily. These people consider it one of the most promising plants ever brought into southern Oregon. It apparently was accidentally introduced with other grass seeds." Again on June 1, 1926, he writes, "This grass I understand produces bulbils under all conditions. At the present time it is growing only in pastures and meadows on land which is not irrigated. This of course is merely accidental. Due to the unprecendented dry season, this grass has already matured and has become perfectly dry and dormant. The roots will revive with cool weather in the fall and produce new growth."

This region was visited by the author and material obtained for analysis. The analyses given in Table 1 help to substantiate the statements of the farmers that the bulbils and the hay are nutritious feed for stock.

TABLE 1.—*Analyses of Poa bulbosa in comparison with other grasses.*

| | Timothy hay, average of 221 analyses* | | Native western bluegrass hay, average of 7 analyses* | | *Poa bulbosa* bulbils, 1 analysis† | | *Poa bulbosa* hay 1 analysis† | |
|---|---|---|---|---|---|---|---|---|
| | Wet % | Dry % | Wet % | Dry % | Wet % | Dry % | Wet % | Dry % |
| Moisture | 11.6 | 00.0 | 8.1 | 00.0 | 8.7 | 00.0 | 12.0 | 00.0 |
| Protein | 6.2 | 7.0 | 11.2 | 12.1 | 7.4 | 8.4 | 5.5 | 6.2 |
| Fat | 2.5 | 2.8 | 3.0 | 3.2 | 6.8 | 7.5 | 3.0 | 3.5 |
| Ash | 4.9 | 5.5 | 8.0 | 8.7 | 10.5 | 11.5 | 5.4 | 6.2 |
| Crude fiber | 29.8 | 33.7 | 29.8 | 32.3 | 9.1 | 9.9 | 26.2 | 29.8 |
| Carbohydrates | 45.0 | 50.9 | 39.9 | 43.3 | 57.4 | 62.8 | 47.6 | 54.1 |
| Total | 100.0 | 99.9 | 100.0 | 99.6 | 99.9 | 100.1 | 99.7 | 99.8 |

*Analyses from Henry and Morrison's *Feeds and Feeding*.

†Analyses by B. A. Madson, Division of Agronomy, Calif. Agr. Exp. Sta., Berkeley, Calif.

The analyses indicate that the bulbils of *Poa bulbosa* are similar to timothy hay in protein content but not so rich as the hay from the western native bluegrasses. The fiber is one-third, more or less, with a considerable increase in the carbohydrates. The fat is over twice as much as that of either timothy hay or the native western bluegrasses.

The common names given to the proliferous form of *Poa bulbosa* are paturin bulbeux in France, Knolliges rispengrass in Germany, fienarola scalogna in Italy, myatlik in Russia, and bulbous meadow grass or bluegrass in English-speaking countries.

As neither *Poa bulbosa* nor its proliferous form is described in American botanical literature, the following will serve to identify it.

## POA BULBOSA

An erect, tufted, perennial grass from 6 inches to 2 feet tall, with the culms tapering at, or near, the base into elliptic-lanceolate bulbs. These bulbs vary in size, seldom exceeding 0.5 inch in length. They are crowded together in tufts at the surface of the ground and multiply by sending forth bulblets laterally. The culms, which terminate in a panicle, have a more slender bulb than those of the innovations. The bulbs are hard and tough when mature and are surrounded by brown, scarious, membranous sheaths. Being well stored with food material, they are capable of withstanding long periods of drought and in this manner functioning as seeds. In summer when the grass tops die the tuft of bulbs and bulblets may become detached from the soil and distributed by the wind.

The leaves are mostly basal and a few inches long; those of the culms numbering about three and shorter. *Nodes*, dark brown; *ligule*, hyaline, whitish, oblong-lanceolate, sub-acute, prominent; (young plants from a bulbil have a very narrow and correspondingly-smaller ligule.) *Sheaths*, more or less dilated near the base; *panicle*, deltoid-ovoid to subcylindrical-ovoid, the branches spreading when in flower and closing later: *spikelets*, 3-to-6-flowered, (Fig. 2, 10); *empty glumes*, acute, the first 1- or 3-nerved, the second 3-nerved; *lemma*, 5-nerved, the marginal and central nerves silky-hairy towards the base; *palea*, 2-keeled, serrulate; *floret*, with a few arachnoid hairs on the axis at the base of the lemma; *stamens*, three; *stigmas*, two, short; *caryopsis*, no fully developed material seen.

European specimens examined show a gradation from complete normal spikelets with stamens and pistil to those in which one or more of the florets in a spikelet are proliferated (Fig. 2, 3). In such material the hairs on the lemma and arachnoid hairs on the axis, may, or may not, be present on some of the florets.

## THE PROLIFERATED FORM

All the specimens of *Poa bulbosa* found growing in the United States show complete proliferation of the spikelets (Figs. 1 and 2). Such plants are generally taller with more profuse panicles. The basal bulbous character of the culms is the same as in the normal form of the species. No stamens or caryopses have been seen by the author, nor is their presence mentioned by other writers. The empty glumes (Fig. 1, 9 and Fig. 2, 1 and 2) are similar to those of the normal spikelet. The next structure (Fig. 2, 3 and 4) has the characteristic form of the first lemma of the normal

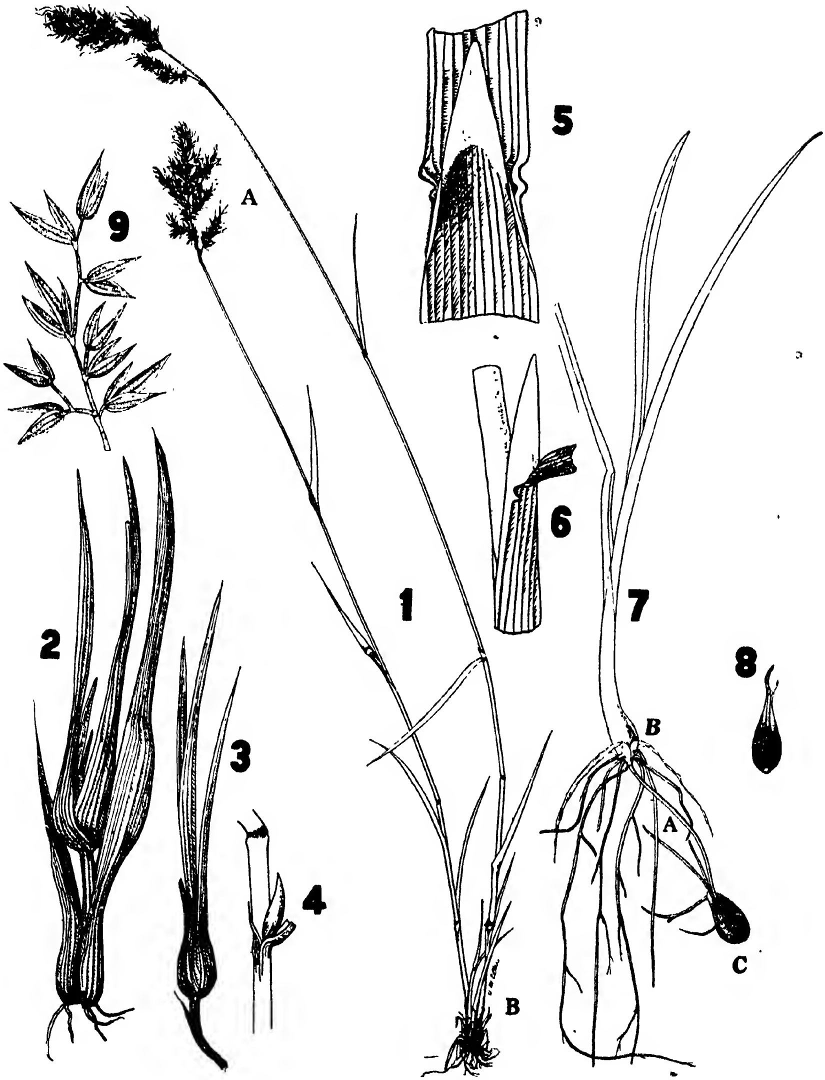


FIG. 1.—Growth and structure of *Poa bulbosa*.

1, *Poa bulbosa* (natural size). A, A proliferated panicle with numerous bulbils. B, Cluster of bulbs at the base of the culms.

2, 3, and 4, Bulblets at the lower nodes also (x 4).

5 and 6, Front and side view of the prominent ligule (x 7).

7, Young plant grown from a bulbil (x 8). A, The elongated axis corresponding to the mesocotyl in the embryo. B, The swollen base of the culm forming the bulb. C, The original bulbil functioning as a seed.

8, A single bulbil (x 8).

9, Part of a panicle of a proliferated spikelet after the bulbils have dropped off

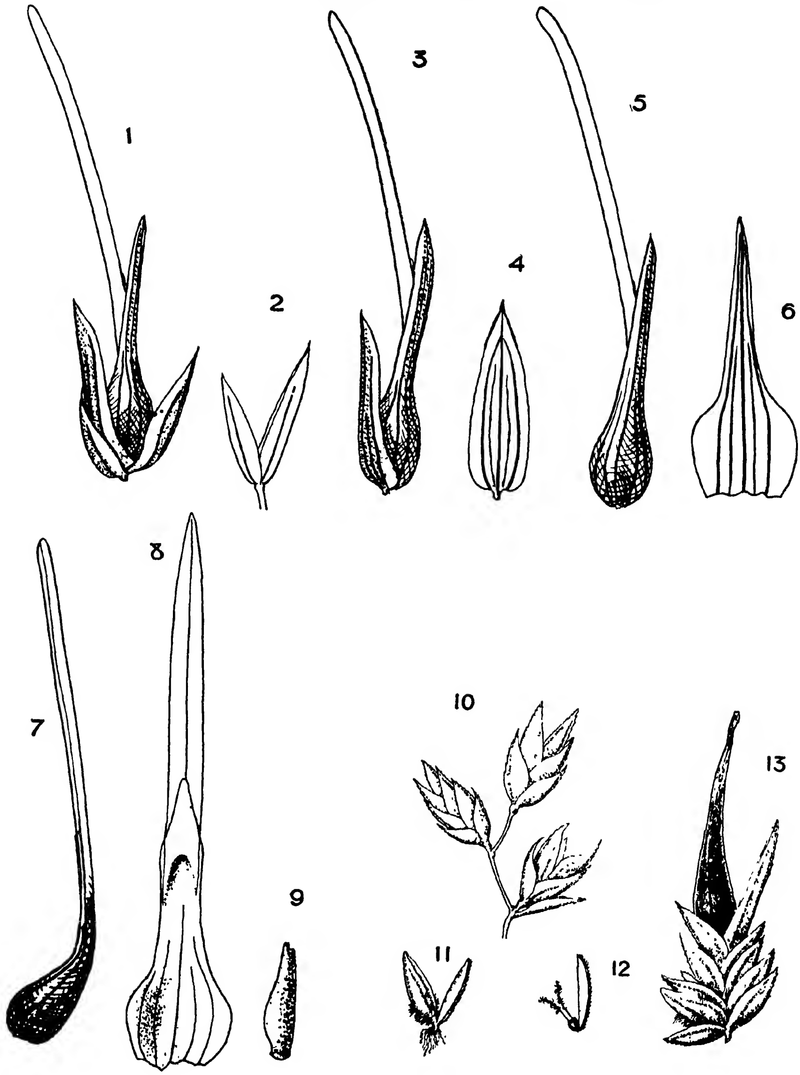


FIG. 2.—Morphology of the bulbil.

1, A complete bulbil (x 10). 2, Empty glumes (x 10). 3, Bulbil with empty glumes removed (x 10). 4, The first lemma spread out (x 10).
5, Bulbil with empty glumes and first lemma removed (x 10).
6, Second lemma spread out (x 10). 7, Elongated third lemma (x 10).
8, Third lemma spread out to show ligule (x 10). 9, The axis within the third lemma (x 10).
10, Normal spikelets (x 8). 11, Lemma and palea of a normal floret (x 8).
12, Palea and ovary of a normal floret (x 8).
13, Spikelet with several normal and one proliferated floret (x 8).

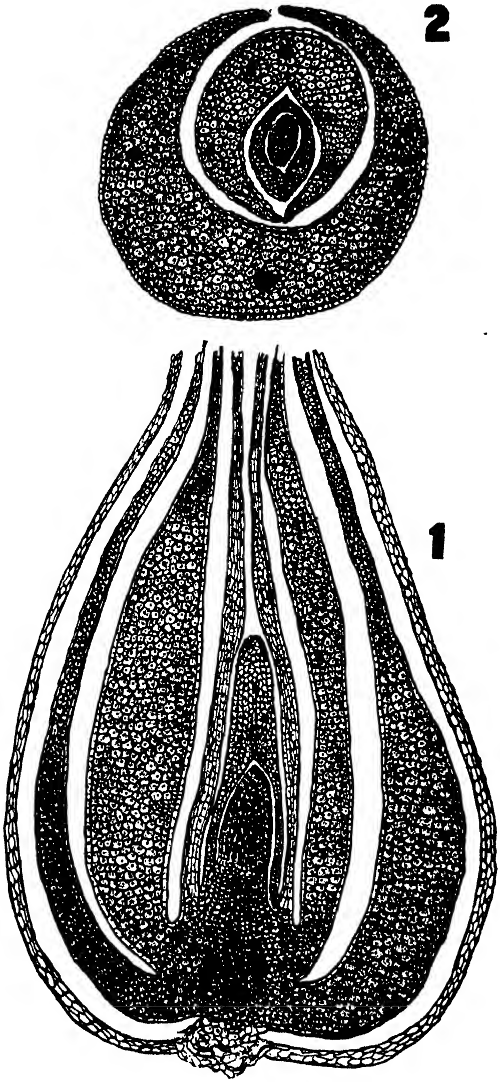


FIG. 3.—Interior structure of a bulbil.
, Longitudinal section (x 170). The central region has a structure similar to that of the plumule, plumule-sheath, first internode or mesocotyl, and radicle found in the embryo of the caryopsis.
, Transverse section (x 170) of a part of the bulbil through the axis, showing the fibrovascular bundles and the distichous arrangement of the lemmas.

spikelet, differing only in being more elongated. It has three prominent nerves and two indistinct ones, one on each side of the central nerve. It does not surround the bulbil completely. No palea accompanies it. Then follows a distinct leaf-like structure completely surrounding the bulbil (Fig. 2, 5 and 6). A prominent ligule (Fig. 2, 7 and 8) is seen in the next structure with the lemma showing the characteristic form of a normal grass leaf. Longitudinal and transverse sections of the bulbil (Fig. 3, 1 and 2) show the alternate distichous arrangement common to the leafy shoots of all grasses and corresponding very closely to the plumule in the embryo of the caryopsis of all Gramineae.

The complete absence of the palea would indicate that the bulbil is a product of the main axis of the spikelet and that the secondary axis which bears the palea and the essential organs is suppressed (Fig. 1, 9 and Fig. 2, 1).

## GROWTH FROM THE BULBILS

The bulbils (Fig. 1, 8) drop from the panicle during the summer and remain dormant until autumn. They appear to have a definite rest period under natural conditions as water applied during the summer does not start growth. The rudimentary plant represented in the bulbil has a central stem or axis, the first internode. This elongates to a greater or less extent, depending upon the depth at which the bulbil is planted. It pushes the plumule ahead of it (Fig. 1, 7A) until the surface is reached when the miniature leaves unfold. At the crown or at the next node above the crown (Fig. 1, 2, 3, and 4) bulbs are formed. Additional lateral innovations appear from the original bulb, each shoot producing another bulb at its base, the final result being a dense cluster of bulbs at the surface of the ground.

Root tissue (Fig. 3, 1) is also represented in the dormant bulbil and when growth commences several roots are sent forth. As the centre of the bulbil is surrounded by layers of miniature leaves, these roots are unable to penetrate them and consequently get out of the bulbil by growing, for a time, in an upward direction and not downward, as would be expected. The outer layers of the bulbil do not grow, but as they are supplied with large quantities of starchy food material they seem to function in a similar manner to that of the scutellum in the embryo of grasses or the cotyledons in some dictoyledonous plants.

The author has not been very successful in getting the bulbils to grow satisfactorily in a standard seed germinator at 23° C when placed in or on the blotters generally used for that purpose. Placing the bulbils in moist sand at various depths from the surface to 1 inch and subjecting them to ordinary room temperature, and to outside conditions where there was an abundance of light did not help matters. In ten days only 4% grew; the others moulding. Attempts to grow them in sphagnum moss also produced negative results. However, bulbils taken from the same lot and planted in soil in the greenhouse or in the open field produced a fair stand both at Davis and at Berkeley.

The weight of the bulbils is 34 pounds to the bushel. In 1 pound of bulbils there were estimated to be 517,840 individuals by counting the actual number in 2 grams. Orchard grass seed comes the nearest to this number in 1 pound of the seed, having 400,000 to 579,500, according to different authors. Computing the rate of planting for *Poa bulbosa* on the same basis as that for orchard grass, 20 pounds of bulbils to the acre would be required for cultivated lands. However, as *Poa bulbosa* is expected to be utilized mainly on ranges a less

amount, probably about 10 pounds, should be sufficient, as time could be allowed for the grass to multiply naturally by aerial bulbils and basal bulbs.

FIG. 4.—A commercial sample of bulbils.

## ECONOMIC CONSIDERATIONS

During the last year there has been much publicity concerning the value of *Poa bulbosa* for forage on the ranges and as a green winter-turf when planted in established Bermuda grass sod of golf courses and lawns. Bulbils have been distributed generously and widely for trial for both of the above-mentioned purposes. Some of the statements from Oregon are to the effect that 50 head of cows were pastured on 10 acres of *Poa bulbosa* from April 1 to the latter part of May, 1927, and that the grass was still flourishing at that time. One ranch owner reports that bulbous bluegrass volunteered in an old stand of alfalfa and yielded a good crop of seed before the first crop of alfalfa reached a sufficient height to be injured. Another report from southern Oregon states that a rancher used an airplane to seed 10 acres with the bulbils, the operation taking only a few minutes.

Yields of bulbils are reported to be from 500 to 700 pounds to the acre.

It would be extremely difficult at this early date to say what the permanent results will be; but if a grass of such high nutritive value and palatability can be made to grow and spread naturally on the millions of acres of foothill lands in California and other western states, the benefit to the livestock industry would be enormous. At the present time much of this area is occupied with plants introduced from Europe, which, for the most part, are weedy annuals of little, or only mediocre, forage value. The only exceptions to this are some of the species of alfilaria (*Erodium*) and the bur-clovers (*Medicago*). A foothill range composed of *Poa bulbosa*, *Erodium cicutarium*, and *Medicago hispida* would be as nearly ideal as could be expected in a section of the country without summer rains.

One of the main objections to a Bermuda-grass lawn is that it turns an unsightly brown in winter due to frost. *Poa bulbosa* remains a pleasing green color even when subjected to frosts. Because of the ease with which Bermuda grass can be grown in all countries with hot summers and cool winters where irrigation is available, it is bound to become popular if the winter-brown of the Bermuda grass can be replaced by the vivid green of bulbous bluegrass during the winter season.

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# METHODS FOR DETERMINING "AVAILABLE" SOIL CALCIUM[1]

H. D. Chapman[2]

## INTRODUCTION

Considerable experimental evidence has shown that the amounts of easily soluble calcium in a soil, when considered in connection with the phosphorus, nitrogen, and potassium supply, may be a better indication of lime need than the acidity and lime requirement methods now in use. It has been an observation in Wisconsin that some acid soils are capable of producing excellent crops of such legumes as alfalfa and the clovers without the addition of lime, whereas many slightly acid sandy soils are incapable of producing successful growth of these legumes without the addition of lime. On the basis of these observations and the knowledge of the important rôle played by calcium in plant nutrition and soil changes, Duley (4, 5)[3] made a study of the relation between easily soluble calcium, soil acidity, and the field growth of legumes. He found in general a closer correlation between the amounts of calcium soluble in N/25 carbonated water and response to lime, on the one hand, than between soil acidity and lime need on the other. At the same time he called attention to the necessity for considering the phosphorus, nitrogen, and potassium supply of a soil in determining lime requirements by this method. Fleetwood (6), in continuing Duley's work, secured similar results. Further data recently secured on Wisconsin soils substantiate these general conclusions.

Shedd (11, 12), Alway and Nygard (1), and many others have reported experiments and observations which emphasize the necessity for considering the calcium supply in soils in connection with the growing of legumes and other crops having a high lime requirement.

[1]Part of a thesis submitted to the faculty of the Graduate School of the University of Wisconsin as partial fulfillment of the requirements for the degree doctor of philosophy. Published with permission of the Director of the Wisconsin Agricultural Experiment Station. Received for publication November 5, 1928.

[2]Formerly Assistant in Soils, University of Wisconsin; now Assistant Chemist, University of California, Citrus Experiment Station, Riverside, California. The writer wishes to express his appreciation for the helpful suggestions and criticisms given by Professor A. R. Whitson, under whose general direction this work was done.

[3]Reference by number is to "Literature Cited," p. 106.

## EXPERIMENTAL

The work reported in this paper represents a preliminary attempt to establish some relation between the amount of calcium which can be extracted by weak solvents, on the one hand, and the amount of calcium which can be removed by plants on the other hand, in the hope that a more rational method for the determination of "available" or easily soluble calcium can be developed.

Two groups of soils were used in this study. The soils represented by one group were from fields in which excellent alfalfa was growing, while those of the other group were from fields where alfalfa was poor or a failure. The former group were soils presumably in no need of lime, while the latter group were those in which alfalfa failure was the result of lime deficiency.

The amounts of calcium removable by carbonated water, by plant seedlings, and by N/1 ammonium chloride (exchangeable calcium) were determined in these soils.

A preliminary study of methods for making carbonated water extractions and exchangeable calcium determinations, together with a study of the value of plant seedlings for indicating differences in calcium content of the soil, was first carried out. The work on each method is described in separate sections, but the final results on the soils studied are assembled in Table 7 and discussed at that point.

## ANALYTICAL METHODS

### DETERMINATION OF CALCIUM

In all soil and plant tissue extracts, calcium oxalate was precipitated in the presence of iron, aluminum, manganese, magnesium, and phosphates at pH 4.0. The details of the method are given in another paper by the author (5).

### DETERMINATION OF H-ION CONCENTRATION

All pH determinations in soils were measured by the quinhydrone electrode, using a 1:2 soil-water ratio, following the procedure, with a few modifications, recommended by Biilman (4). The colorimetric method was used in determining the pH of carbonated water. Clark and Lub's buffer mixtures were used.

### DETERMINATION OF PHOSPHORUS

The available phosphorus determinations on soils were made as follows: Twenty grams of soil were shaken with 200 cc of N/5 $NHO_3$ for 10 minutes and the suspension quickly filtered. Phosphorus was determined colorimetrically in the filtrate by an improved method of Meyer and Truog (15).

## CARBONATED WATER FOR DETERMINING EASILY SOLUBLE CALCIUM IN SOILS

It is well known that the carbonated water in soils, formed through the excretion of $CO_2$ by plants and through biological activity, exerts appreciable solvent actions on soil minerals. Use of this solvent seems amply justified by reason of its presence in the soil and its possible function in plant nutrition.

The method used by Duley (4) for determining easily soluble calcium and continued for some time in this laboratory consisted in shaking a suspension of 12 grams of soil in 600 cc of N/25 carbonic acid for 2 hours. Calcium was then determined in 500 cc of the filtered extract. The chief objections to this method are (a) its empirical nature and (b) the rapid decomposition of the carbonic acid especially accentuated by shaking.

Preliminary trials in which soil suspensions were aspirated with $CO_2$ did not prove particularly successful. More satisfactory and perhaps less empirical results seemed possible by leaching soils in a closed system with a saturated solution of carbonated water. This method possesses the following advantages: (a) The concentration of carbonic acid is kept constant, except for slight variations due to daily temperature and pressure changes; and (b) leaching constantly removes one of the products of reaction simulating therefore the condition which presumably obtains when a plant feeds. It seems possible that the soil solution in the localized zone of contact between a root hair and soil particle could become saturated with the $CO_2$ excreted by plant roots and hence develop the same solvent action for calcium as the solution used for leaching. If this be true, the easily soluble calcium removed by leaching should correlate somewhat with the growth of alfalfa in cases where calcium is the limiting element, and likewise should bear some relation to the amounts of calcium capable of being removed by plants under controlled conditions.

A description of the apparatus for leaching soils with a saturated solution of carbonic acid in a closed system is as follows: The carbonated water, contained in a tall glass carboy, was kept saturated by continually passing a stream of purified $CO_2$ through it. A Gooch funnel was made into a filtering device by placing a perforated porcelain disc in the bottom where the funnel narrows down, and covering with asbestos. Soil was placed on top of this and the funnel fitted with a rubber stopper and glass tubing by which it was connected to an opening in the bottom of the carboy. By placing this bottle in a high position, sufficient pressure was developed to force

the solution through the soil easily, thereby eliminating a need for suction. The rate of leaching was regulated by screw clamps and the leachings were collected in graduated bottles. Using appropriate connections, a series of six funnels were connected to the one carboy. Determinations of the concentration of $CO_2$ in various parts of the system prior to contact with soil gave identical values. The solution was 0.0554 N and had a pH of 3.9 at a room temperature of 20°.

Preliminary experiments were first conducted to determine what amounts of calcium are removed by different rates of leaching, the reproducibility of determinations, and the total amount of calcium capable of being leached out of a soil by this reagent.

### EFFECT OF RATE OF LEACHING

Five hundred cc of the solution were leached through portions of the same soil at different rates by regulating the screw clamps. The data obtained are given in Table 1.

TABLE 1.—*Effect of rate of leaching on calcium removed.*

| Time for 500 cc of carbonated water to leach through soil | Calcium in leachate in p.p.m. |
|---|---|
| 30 minutes | 550.0 |
| 1½ hours | 600.0 |
| 2 hours | 634.0 |
| 3 hours | 755.0 |
| 9 hours | 750.0 |

The data on this soil show that a considerable portion of the calcium goes into solution rapidly and that something in the nature of an equilibrium between the calcium compounds and the carbonated water is established when the rate of leaching is such that it takes between two and three hours for 500 cc to pass through. Obviously, if comparative results with the same soil and other soils are to be obtained where only the first 500 or 1,000 cc are to be analyzed for calcium, the same rate of leaching must be employed.

In order to find out how closely the results could be duplicated, two soils, one high in calcium and one low, were leached at the rate of 1,000 cc per 5 hours, and this first liter analyzed. The results given in Table 2 show sufficient agreement for all practical purposes.

TABLE 2.—*Duplicates obtained by leaching method.*

| Soil No. | Calcium in first 100 cc of leachate in p.p.m. |
|---|---|
| 329A | 495.0 |
| | 510.0 |
| 323A | 2100.0 |
| | 2110.0 |

## AMOUNTS OF CALCIUM OBTAINED FROM SUCCESSIVE LEACHINGS AND TOTAL CALCIUM CAPABLE OF BEING DISSOLVED BY SATURATED CARBONATED WATER

In order to find out what amounts of calcium are removed by successive portions of the solution and how much calcium can be removed from soils by this solvent, a determination of calcium and pH was made in successive liters of the leachings. Two soils, one high and one low in calcium, were used. The results are recorded in Table 3.

TABLE 3.—*Amounts of calcium removed by successive portions of carbonated water and the pH of the leachings.*

| Soil No. 224 | | | Soil No. 212 | | |
|---|---|---|---|---|---|
| Successive liters | Calcium in p.p.m. | pH of leachings | Successive liters | Calcium in p.p.m. | pH of leachings |
| 1 | 896.0 | 4.7 | 1 | 1,805.0 | 4.8 |
| 2 | 269.0 | | 2 | 663.0 | 4.5 |
| 3 | 161.0 | | 3 | | |
| 4 | 127.0 | | 4 | 642.0 | 4.5 |
| 5 | 76.0 | | 5 | | |
| 6 | 50.0 | | 6 | 245.0 | 4.4 |
| 7 | 50.0 | | 7 | | |
| 8 | 32.0 | | 8 | 234.0 | 4.2 |
| 9 | 15.0 | | 9 | | |
| 10 | 6.0 | 3.9 | 10 | 194.0 | 4.1 |
| 11 | | | 11 | | |
| 12 | | | 12 | 105.0 | 4.0 |
| 13 | | | 13 | 50.0 | 4.0 |

It appears from these results that all of the calcium capable of being removed by carbonated water is leached out with from 10 to 13 liters. When the pH of the extract is the same as the reagent, it indicates that all of the calcium capable of being removed by a reagent of this H-ion concentration has been extracted.

Upon the basis of these findings relative to the rate of leaching and total amount of carbonated water needed to remove most of the calcium, the series of soils chosen for this study were leached with carbonated water in the manner described. Calcium was determined in the first liter of leachate and the total calcium leached out likewise determined. The results are recorded in Table 7.

## DETERMINATION OF EXCHANGEABLE CALCIUM

The method most commonly used in this country for determining replaceable bases in neutral or acid soils is essentially that which has been used by Kelley and Brown (8). They digest 25 grams of soil with 250 cc of N/1 $NH_4Cl$ (pH 7.0) at 70° overnight. The soil is then filtered and leached with $NH_4Cl$ to 1,000 cc. Replaceable

bases are determined in aliquots of this leachate. Since calcium was the only base to be determined in these soils, it was thought possible to modify this method slightly. Preliminary tests were made, therefore, to determine the relative effect of the amount of leaching, time of digestion, effect of heating, and the amount of soil on the amounts of calcium removed. The results of these tests indicated that the bulk of the calcium is removed from 25 grams of soil by leaching to 500 cc and that prolonged digestion and heating brings only slightly more calcium into solution. By using 10 grams of soil, shaking for a short time, and leaching to 500 cc with N/1 $NH_4Cl$ it was found that the results were practically identical to those obtained by the method of Kelley and Brown. The data obtained by this method as compared with those obtained by using 25 grams of soil, digesting at 70°, and leaching to 1 liter are recorded in Table 4.

TABLE 4.—*Comparison of methods for removing exchangeable calcium.*

| | Calcium, M. E. per 100 grams soil | |
|---|---|---|
| Soil No. | Method of Kelley and Brown | Modified method |
| 114 | 17.03 | 17.62 |
| | 17.03 | 17.59 |
| 126 | 4.28 | 4.33 |
| | 4.25 | 4.25 |
| 109 | 5.97 | 6.00 |

Replaceable calcium was determined in the group of soils selected for this work by the modified method and the data are recorded in Table 7.

## REMOVAL OF CALCIUM FROM SOILS BY PLANT SEEDLINGS

Neubauer (10) has developed a test for determining the availability of plant food elements in the soil. The test is based on the supposition that a large number of plants grown for a short period in a small amount of soil will extract an amount of each element somewhat proportional to the total available supply in the soil. Neubauer claims to have secured good correlation between the results observed in the field and those obtained with this method. Numerous investigators have utilized Neubauer's principle and some have secured results in accord with the principle suggested, others not.

In considering methods for determining available calcium in soils it was thought that this method might be of value.

### EFFECT OF LIME IN INCREASING CALCIUM CONTENT OF PLANTS AND COMPARATIVE AMOUNTS OF CALCIUM REMOVED BY VARIOUS PLANTS

Preliminary experiments were carried out to find out which plants might be best adapted relative to the rapidity of growth and effectiveness in removing calcium. Lime was added to one series in order to ascertain whether differences in calcium content of the soil would be reflected in plant composition. The details as proposed by Neubauer were employed except that a nutrient solution of $K_2HPO_4$ brought to pH 6.2 by $HNO_3$ was added to all except the check pots. The nutrient solution added to each pot contained the following elements expressed in milligrams: 0.416 K, 0.135 P, and 0.199 $HNO_3$.

Lime in the form of C. P. $CaCO_3$ was supplied at the rate of 3,000 pounds per acre on one series. Both series were run in duplicate on a sandy soil low in calcium. Alfalfa, barley, rye, buckwheat, radish, and sorghum were grown. Alfalfa was grown 33 days, the others 17 days. In harvesting, the plants were washed free of sand and soil, dried, weighed, and the calcium in the entire amount of plant tissue from each pot determined. The results secured are given in Table 5.

TABLE 5.—*Calcium removed by alfalfa, barley, rye, buckwheat, radish, and sorghum from limed and unlimed soils.*

| | Unlimed | | Limed | |
|---|---|---|---|---|
| Crop | Weight of crop in grams | Calcium removed from soil in p.p.m. | Weight of crop in grams | Calcium removed from soil in p. p.m. |
| Alfalfa | 0.2892 | 0.7 | 0.3966 | 27.2 |
| Rye | 1.5530 | 27.9 | 1.5519 | 76.7 |
| Barley | 1.8180 | 34.7 | 2.1155 | 91.0 |
| Sorghum | 1.4737 | 40.7 | 1.2988 | 93.0 |
| Buckwheat | 1.9757 | 92.3 | 1.8873 | 148.0 |
| Radish | 0.9908 | 109.5 | 1.0898 | 259.0 |

Barley, rye, and buckwheat made the most rapid growth. Liming caused a slight increase in the total growth of alfalfa, barley, and radish and markedly increased the calcium absorption by all the plants. This indicates definitely that, under the conditions of this experiment, any of these plants will reflect in their composition differences in the calcium content of the soil. Alfalfa, buckwheat, and radish remove the largest amounts of calcium from the soil per gram of dry matter.

Another experiment was set up in which barley seedlings were grown on soils coming from limed and unlimed portions of the same field. The field growth of alfalfa on these soils was a failure on the un-

limed portions and a success on the limed portions. The same technic as used in the preceding experiment was employed. The weights of barley and the total calcium removed from the soil, as shown in Table 6, are averages of triplicates. Previous determinations of easily soluble calcium by the N/25 carbonic acid method had been made on these soils, and are included in Table 6.

The most significant results secured in this experiment are the outstanding increases in calcium content of the barley from the fields which had been limed and were growing good alfalfa. This would be expected from the results secured in the first experiment. As compared with the amounts of calcium taken out by carbonated water that removed by barley is much less, but it is of the same order in most cases.

From the results of the foregoing experiments several changes in technic appeared desirable. The roots of all crops tend to concentrate in the bottom of the pots and it was thought that a greater extraction of calcium could be obtained by reducing the amount of soil used.

By supplying an excess of nitrogen, potassium, and phosphorus, differences in fertility which naturally affect the extraction of calcium would tend to be lessened and would enable the plant to feed more heavily on the calcium in soils low in the available supply of these elements. Finally, by employing buckwheat, which grows rapidly, germinates well, and feeds heavily on calcium, it was thought that conditions would be provided for the maximum extraction of this element.

In order to find out whether under these conditions buckwheat seedlings could remove any more calcium from a soil than is removable by carbonated water, a sandy soil was leached with carbonated water until most of the calcium was removed. This soil was then included with the other soils used in this experiment.

The details of the technic employed in this series are given in full. The following amounts (milligrams) of potassium and phosphorus in solution as $K_2HPO_4$ adjusted to pH 6.0 by $HNO_3$ were supplied to each pot, part at the beginning and part during the growing season:

| Time of application | Sandy soils | | | Silt loam soils | | |
|---|---|---|---|---|---|---|
| | K | P | $HNO_3$ | K | P | $HNO_3$ |
| Beginning | 0.207 | 0.067 | 0.114 | 0.332 | 0.105 | 0.182 |
| 20 days later | 0.415 | 0.134 | 0.228 | 0.415 | 0.134 | 0.228 |

The addition of nutrients was not entirely effective, for soil differences in a few cases were apparent in spite of these plant food additions to all pots. More nutrients could have been applied at

TABLE 6.—*Removal of calcium by barley seedlings and by N/25 carbonic acid from soils whose field response to lime is known.*

| Soil No. | Soil type | Field lime treatment | Field growth of alfalfa | Dry weight of barley seedlings in grams | Calcium removed from soil by barley in p.p.m. | Calcium removed by N/25 $H_2CO_3$ in p.p.m. |
|---|---|---|---|---|---|---|
| 302 | Plainfield sand | No lime | Failure | 2.0059 | 9.9 | 129.0 |
| 303 | Plainfield sand | 3 tons lime sludge | Excellent | 2.2922 | 85.0 | 1027.0 |
| 309 | Plainfield sand | No lime | Failure | 2.1774 | 2.3 | 134.0 |
| 310 | Plainfield sand | 3 tons lime sludge | Excellent | 2.2346 | 35.7 | 532.0 |
| 232 | Carrington silt loam | No lime | Poor | 2.1919 | 19.4 | 205.0 |
| 231 | Carrington silt loam | H. T. lime | Good | 2.1602 | 32.3 | 432.0 |
| 126 | Colby silt loam | No lime | Poor | 2.2032 | 8.0 | 140.0 |
| 127 | Colby silt loam | Lime | Excellent | 2.1161 | 23.1 | 196.0 |

the beginning and soon after good growth started without danger of injury.

Fifty grams of silt loam soil were mixed with 25 grams of acid-washed quartz sand. No quartz sand was added to the sandy soils. After weighing out the soils into their respective containers, 20 cc of nutrient solution for the silt loam soils and 10 cc for the sandy soils, containing in each case the above specified amounts of nutrients, were mixed thoroughly with the soil. After leveling the mixture, 160 grams of quartz sand were placed on top, moistened with 30 cc of distilled water, and 120 seeds planted. Then 90 grams of quartz sand were placed on top of the seeds and an additional 25 cc of distilled water added. The pots were covered until the seeds had germinated. They were then directly thinned to 100 seedlings per pot. The pots were watered two or three times a day, depending upon the size of the plants and the greenhouse temperature. By careful observation, the moisture was controlled more satisfactorily than by originally weighing the pots and keeping the pots up to weight, a tedious and somewhat faulty procedure. At the end of 34 days the buckwheat seedlings were harvested, washed free of soil, dried. weighed, and analyzed for calcium.

The technic employed in the latter series appears to be superior, for the purposes of this experiment, to the technic used in the preceding experiments. The results given below show the comparative amounts of calcium removed by buckwheat seedlings from the same soil in which different amounts of soil and a different period of growth constitute the chief difference in technic:

| Soil | Calcium in p.p. removed from soil: 100 grams of soil used, buckwheat grown 17 days | 50 grams of soil used, buckwheat grown 34 days |
|---|---|---|
| Plainfield sand | 148.0 | 215.0 |

The results secured by the use of this method on the group of soils in which the calcium soluble in carbonated water and N/1 $NH_4Cl$ (exchangeable calcium) had been determined are given in Table 7.

In an attempt to supplement the field information concerning the fertility of these soils and to explain why some soils comparatively low in calcium produced good alfalfa in the field and some soils high in calcium produced poor alfalfa, determinations of available phosphorus were made and are recorded in Table 7 along with the other data.

TABLE 7.—*Comparison of the amounts of calcium removed from soil by carbonated water, N/1 $NH_4Cl$ (exchange calcium), and buckwheat seedlings.*

| Soil No. | Soil type | Field growth of alfalfa | Available phosphorus in p.p.m. | Calcium removed by carbonated water extractions: N/25 method in p.p.m. | Leaching first liter in p.p.m. | Leaching total removed in p.p.m. | Total exchange calcium in p.p.m. | Calcium removed by buckwheat seedlings in p.p.m. |
|---|---|---|---|---|---|---|---|---|
| 128 | Colby silt loam | Poor | 6.5 | 25.4 | 438.0 | 800.0 | 943.0 | 344.0 |
| 100 | Plainfield sand | Poor | 14.0 | 107.0 | 255.0 | 367.0 | 446.0 | 215.0 |
| 100 | Plainfield sand (leached) | — | — | 25.0 | 47.0 | — | — | 52.2 |
| 126 | Colby silt loam | Poor | 7.5 | 140.0 | 500.0 | 850.0 | 856.0 | 320.0 |
| 134 | Knox silt loam | Poor | 4.5 | 175.0 | 520.0 | 1,345.0 | 1,845.0 | 319.0 |
| 238 | Miami silt loam | Poor | 5.5 | 201.0 | 492.0 | 993.0 | 1,081.0 | 423.0 |
| 232 | Carrington silt loam | Poor | 6.5 | 205.0 | 826.0 | 2,091.0 | 2,340.0 | 378.0 |
| 329 | Knox silt loam | Poor | 4.0 | 217.0 | 510.0 | 917.0 | 1,160.0 | 336.0 |
| 124 | Colby silt loam | Poor | 6.5 | 247.0 | 825.0 | 1,507.0 | 1,414.0 | 526.0 |
| 251 | Miami silt loam | Poor | 12.0 | 433.0 | 1,121.0 | 2,309.0 | 2,022.0 | 503.0 |
| 13 | Carrington silt loam | Excellent | 30.0 | 196.0 | 709.0 | 1,551.0 | 1,820.0 | 527.0 |
| 109 | Colby silt loam | E. cellent | 14.0 | 215.0 | 631.0 | 702.0 | 1,195.0 | 536.0 |
| 602B | Colby silt loam | Good | 15.0 | 319.0 | 868.0 | 2,001.0 | 1,975.0 | 456.0 |
| 214 | Carrington silt loam | Good | 8.7 | 406.0 | 1,040.0 | 2,420.0 | 2,680.0 | 558.0 |
| 16 | Carrington silt loam | Excellent | 35.0 | 454.0 | 2,040.0 | 3,325.0 | 2,682.0 | 667.0 |
| 120 | Colby silt loam | Excellent | 60.0 | 497.0 | 1,340.0 | 2,449.0 | 2,311.0 | 668.0 |
| 333 | Knox silt loam | Excellent | 125.0 | 497.0 | 1,359.0 | 2,634.0 | 2,590.0 | 663.0 |
| 224 | Miami silt loam | Good+ | 124.0 | 498.0 | 989.0 | 1,727.0 | 2,030.0 | 510.0 |
| 212 | Knox silt loam | Excellent | 204.0 | 640.0 | 1,680.0 | 3,934.0 | 4,120.0 | 569.0 |
| 323 | Colby silt loam | Excellent | 16.0 | 1,356.0 | 2,100.0 | 3,483.0 | 3,405.0 | 864.0 |

## DISCUSSION OF DATA

A comparison between the field growth of alfalfa and the amount of calcium removed by any of the methods shows in most soils that those producing a successful growth of alfalfa are higher in calcium than those in which alfalfa is poor. There are several soils in which there appears to be an adequate supply of calcium where alfalfa is poor and a few other soils in which the supply of calcium appears inadequate where growth is good.

Low phosphorus supply in soils 251, 124, and 232 probably partially accounts for the poor alfalfa in spite of a fairly good calcium supply, whereas a better phosphorus supply and probably other accompanying favorable fertility factors account for the good alfalfa growth on soils 13, 109, 602B, and 214. The calcium content of these seven soils is probably sufficient under favorable fertility conditions and ineffective under unfavorable fertility conditions.

It will be noted that the total amounts of calcium capable of being leached out of a soil by carbonated water are close to, and in some cases practically identical with, the exchangeable calcium. This is further confirmation of the generally accepted belief that acids of sufficient weakness to preclude decomposing action on silicates can probably be used as well as neutral salts for determining replaceable bases, as suggested by Gedroiz (7) and by Kelley and Brown (8).

While the exchangeable calcium and total calcium removable by carbonated water may indicate the potential supply of calcium in a soil which might be usable by a plant, yet it may not necessarily indicate the more available portion of this supply. If, as is suggested by the data presented herein, the absorption of calcium by plant seedlings is an indication of the easily available supply in a soil, the total exchangeable calcium is not a reliable measure of availability. From the small amount of data presented it appears that there is less correlation between alfalfa growth in the field and exchange calcium than between the amount of calcium removed by the first liter of carbonated water leachings and alfalfa growth.

As a measure of the more easily soluble or available calcium that portion taken out by the first liter of leaching offers some advantages which may justify its use as an arbitrary standard. In many cases it will be noted that roughly half of the total calcium removable is extracted by the first liter. Such information offers some indication of the potential supply of calcium a soil may have, an important point in considering the continued capacity of a soil to furnish sufficient calcium for plant needs and hence important in indicating when the soil will likely need to be limed. With the exceptions noted pre-

viously, considerably higher amounts of calcium are found in the first liter of leachate in soils producing good alfalfa than in those producing poor alfalfa. The results obtained by using N/25 carbonated water, as previously described, are more consistent in being lower on the poor soils and higher on the good soils, but do not show in all cases the differences in potential supply as indicated by the first liter of leaching.

In comparison with the amounts of calcium extracted by buckwheat seedlings that removed by use of the N/25 method in all but two cases is lower, while that removed in the first liter of leachate is higher. On the basis of these results it appears that the calcium removed by the first liter of carbonated water leachings, as compared to the calcium removed by extraction according to the N/25 method, offers the following advantages: (a) Accuracy, (b) an indication of the total potential supply of soil calcium, and (c) some measure of the easily soluble and quickly available calcium.

Turning to the results obtained with buckwheat seedlings as extracting agents for soil calcium, several points are of interest. One of the important results is the wide range of calcium extraction varying from 52.2 p.p.m. to 864.0 p.p.m. There was of course about 40% more growth in the latter case due probably both to greater calcium content and to better fertility. The results are nevertheless important in indicating the possible value of this method in determining the quantity of available caclium a soil may contain. Most of the analyses show a calcium removal of from 300 to 600 p.p.m., a difference which is sufficient to be significant. Of particular interest is the result on soil 100, which had been previously leached with carbonated water to remove most of the calcium. The buckwheat plants were able to remove only 52.2 p.p.m. of calcium and further leaching with 1 liter of carbonated water removed 47 p.p.m. This result may not be significant, but it is nevertheless suggestive of a possible connection between the H-ion concentration of the soil and the ability of a plant to secure basic elements from the soil.

Determinations of pH were made on several of the soils which had been leached with saturated carbonated water (pH 3.9) until practically all of the calcium had been removed. These soils were found to have an acidity of about pH 4.0. Theoretical reasoning leads to the conclusion that when the H-ion concentration of the soil reaches the same value as that of the extracting agent no more exchange of H-ions for basic ions will take place, even though the soil still contains replaceable basic ions. The experimental results reported support this theory. If it be assumed that the $CO_2$ secreted by plant roots is

of major importance in bringing plant food elements into solution, it is obvious that the amount of basic elements which can be obtained from the soil will be dependent upon the acidity of the solution developed by the plant root in the zone of contact between the root hair and soil particle. Probably long before the soil comes to the same acidity as that developed by the plant root, the supply of base becomes diminished to the point where the plant is unable to secure base at a sufficient rate to support normal growth.

While the results secured in this study are but meager and preliminary in nature, they suggest that a study of the availability of calcium with respect to the degree of saturation of the soil might offer very important clues as to the nature of plant feeding. To this end, the seedling method appears to possess considerable merit and might be used to pave the way to the development of more precise chemical methods.

## SUMMARY

A preliminary study of methods for determining easily soluble calcium is reported. The use of carbonated water as a solvent possesses theoretical significance, but has disadvantages by reason of its instability. Leaching soils with saturated carbonated water in a closed system proved a satisfactory means of using this reagent. A slight modification of the $NH_4Cl$ method for determining exchangeable calcium is given. Utilization of the seedling method, advanced by Neubauer, for determining the availibility of soil constituents was found useful in indicating the amounts of easily soluble calcium a soil may contain. The chief points of interest brought out by this study are as follows:

1. All the methods show in general a higher calcium extraction from soils growing good alfalfa than from those growing poor alfalfa. The exceptions are probably due to the influence of other fertility conditions.

2. The total amounts of calcium leached out by carbonated water were found to approximate closely the exchange calcium in the soils. While the determination of such total amounts is important in indicating something as to the potential supply of usable calcium a soil may contain, it does not furnish evidence as to that portion which must be available to enable a plant to maintain normal growth.

3. The calcium leached out by the first liter of saturated carbonated water shows something as to potential supply, represents the more easily soluble calcium, and shows considerable correlation to field results with alfalfa. Leaching with saturated carbonated water in a closed system is more accurate than shaking given quantities of soil

and N/25 $H_2CO_3$ and determining the calcium dissolved. The former procedure approaches more nearly to the hypothecated mechanism of plant feeding and possesses, therefore, more significance as a method for determining so-called available calicum.

4. The extraction of calcium by means of plant seedlings offers interesting possibilities in determining the relative amount of easily soluble constituents in a soil. Used in conjunction with chemical methods, it enhances their significance in determining that portion of an element which is available. Not as wide a range of calcium could be removed from the soil by buckwheat seedlings as by carbonated water, but the results obtained were in somewhat the same order and amounts.

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# BOOK REVIEW

## THE AGRICULTURAL DEVELOPMENT OF ARID AND SEMI-ARID REGIONS, WITH SPECIAL REFERENCE TO SOUTH AFRICA

*By H. D. Leppan. Johannesburg Central News Agency, Ltd. XIV + 280 pages. 1928. £ 1, 5.*

The title of this work suggests a general treatise on the development of agriculture in semi-arid regions, but the main purpose of the book is found in the very obvious effort to draw from the best practices in other semi-arid regions those which will be most available to the South African farmer. A difficult problem exists in the development of South African agriculture, presenting unique and peculiar phases in (1) climate, (2) soil, (3) transportation, and (4) population, not duplicated elsewhere.

Climatic factors, especially in the distribution of the rainfall determine the limits of agriculture. The total area, which lies mainly in the south temperate zone, is divided naturally into two divisions, *viz.*, (1) a rather narrow strip along the southwest and south coast, with a wet season in winter followed by a dry summer season like that of California, and (2) a much larger area in which the principal rains fall during the summer season. The rains falling during the winter in the first area are largely effective in the production of crops like the small grains, while in the latter region the summer rains favor summer crops of maize, sorghums, and grasses. The storms which bring rains in the winter come from the south Pacific, while those which bring the summer rains arise in the Indian Ocean to the east. No very high ranges of mountains aid in catching and condensing these moisture ladened winds. The principal soil areas lie back from the coast in both divisions, in high plateaus from which the precipitated moisture rapidly runs off. Evaporation appears to be far in excess of that occurring in most of the other semi-arid regions of Australia, western United States, and Bombay, which are used in comparison throughout the book. On the higher plateaus frost and hail are frequently limiting factors in cropping.

Irrigation is limited to a possible 3,000,000 acres, and is beset with difficulties common to all irrigated areas, namely, high cost of land and development, inexperienced farmers, transportation, alkali, and drainage.

The soil of South Africa is not very fertile, due perhaps to the washing out of the tablelands over long periods of time. Under the continuous cropping systems prevailing, crop yields have run down until the acre yields of small grains, maize, and sorghum fall far below those prevailing in other countries similarly situated.

The basis of agriculture lies in the production of livestock. Vast areas in South Africa are suited to range cattle, sheep, and goats, but the carrying capacity of the land is low. Poor native breeds mitigate against exportation in competition with better bred stock. Much improvement in stock breeding has occurred, but the large numbers of animals in the hands of the native population make the

process very slow. So far as farming is concerned, its future must depend upon stock raising as the backbone of the industry. Dairying will increase with the population. Irrigated areas will supply feed to carry over and fatten stock produced on the range. In certain areas fruits, especially citrus, will be exported with profit.

On the whole, the future of agriculture does not look highly promising from an American viewpoint, and in the end the rapidly growing native population may consume all the general agricultural products produced. Land tenure of both native Indian and European stocks is discussed.

The book clearly presents the agricultural problems of South Africa in such a concise manner that one cannot help but be impressed with the clear-sighted investigations being conducted by agricultural scientists situated in the various institutions in the area. (W. W. M.)

# AGRONOMIC AFFAIRS

## RECOMENDATIONS WITH REFERENCE TO FERTILIZATION OF TOBACCO GROWN ON AVERAGE SOILS IN VIRGINIA, NORTH CAROLINA, SOUTH CAROLINA, AND GEORGIA DURING 1929

### I. FERTILIZERS FOR BRIGHT FLUE-CURED TOBACCO

1. Analyses of Mixtures:

   1. *For heavy or more productive soils.*—Eight per cent available phosphoric acid, 3% ammonia, and 5% potash, except for gray soils with red subsoils of the Cecil series of Virginia where 8% available phosphoric acid, 3% ammonia, and 3% potash is recommended.

   2. *For light or less productive soils.*—Eight per cent available phosphoric acid, 4% ammonia, and 6% potash.

2. For Control of "Sand-drown" (Magnesia Hunger):
For sections where "sand-drown" is prevalent, it is recommended that fertilizers carry 2% magnesia (MgO). This may be derived from sulfate of potash-magnesia, dolomitic limestone, or any other material carrying magnesia in forms known to be available to the plant.

3. Amount of Fertilizer:
Use 800 to 1,200 pounds per acre in the drill thoroughly mixed with the soil just before transplanting.

4. Sources of Plant Food Constituents:

   1. *Phosphoric acid.*—Derived from superphosphate.

   2. *Potash.*—Derived from a combination of high-grade muriate of potash with either high-grade sulfate of potash or sulfate of potash-magnesia, or both.

Available experimental data at this time from bright tobacco sections of Virginia, North Carolina, South Carolina, and Georgia show that a small quantity of chlorine in the tobacco fertilizer increases the acre value of the crop. Experience has shown, however, that an excessive amount of chlorine in fertilizers used for tobacco injures its growth, producing a thick brittle leaf, and also has an unfavorable effect upon its burning quality. It is recommended, therefore, that fertilizers be compounded with the above-named sources of potash in such proportions that the fertilizer mixtures shall contain a maximum of 2% of chlorine. Since research has shown that heavier applications of high-grade potash are profitable, it is recommended that the potash content of mixed fertilizers exceed that of ammonia by at least two units, except for gray soils with red subsoils of the Cecil series in Virginia.

3. *Ammonia.*—One-half of the ammonia should be derived from high-grade organic materials of plant or animal origin, such as cottonseed meal, fish scrap, and high-grade tankage. The remaining half should be derived from urea and standard inorganic sources of nitrogen, such as nitrate of soda and sulfate of ammonia, at least one-fourth of the total ammonia being supplied by nitrates.

## II. FERTILIZERS FOR DARK TOBACCO (SUN-CURED AND SHIPPING)

1. Analyses of Mixtures:
Use 8% available phosphoric acid, 3% ammonia, and 3% potash.
2. Amount of Fertilizer:
Use 600 to 1,000 pounds per acre in the drill at or just before transplanting.
3. Sources of Plant Food Constituents:

1. *Phosphoric acid.*—Derived from superphosphate.

2. *Potash.*—Derived from sulfate of potash-magnesia, high-grade muriate of potash, or high-grade sulfate of potash.

3. *Ammonia.*—One-half of the ammonia should be derived from high-grade organic materials of plant or animal origin, such as cottonseed meal, fish scrap, and high-grade tankage. The remaining half should be derived from urea and standard inorganic sources of nitrogen, such as nitrate of soda and sulfate of ammonia, at least one-fourth of the total ammonia being supplied by nitrates.

C. B. Williams, North Carolina, *Chairman*
T. B. Hutcheson, Virginia, *Secretary*
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L. G. Willis, North Carolina
R. E. Currin, Jr., North Carolina
T. S. Buie, South Carolina
R. E. Currin, Sr., South Carolina
E. C. Westbrook, Georgia
J. M. Carr, Georgia
W. F. Pate, Soil Improvement Committee

## REPORT OF COMMITTEE ON TERMINOLOGY[1]

At the annual meeting of the Society in 1927 your committee reported with favorable recommendation a method of forming median terms in a series of adjectives of comparison, and also recommended the formation of regular English plurals for Anglicized Latin nouns for which the Latin plurals still are used. A paper entitled "Median Terms in Adjectives of Comparison," was published in the February, 1928, issue of the JOURNAL, and a paper entitled "English or Latin Plurals for Anglicized Latin Nouns," was published in *American Speech*, 3(4):291–325, April, 1928. Reprints of the latter were supplied by the Society for distribution.

During the year the Chairman of the Committee has given a great deal of attention to the use of the infinitive "to dehull," meaning to remove hulls from seeds, and to the corresponding term "hulled," meaning to possess hulls. Some writers use the term "hulled" in the sense of "having the hulls removed." The past tense of many hundreds of similar verbs has only the one meaning of indicating the possession of the article or quality named. Comparable examples are such words as baited, clothed, capped, crowned, glazed, hinged, iced, limed, painted, plastered, polished, tempered, and windowed.

That this is the common usage is indicated in several other ways than by the use of the past tense of the verb with the meaning named. It is shown by the use of the prefix "de," applied to many such roots, and having the infinitive meaning "to remove" or "to deprive of" the article or quality indicated. Such words as decolor, deforest, degerm, degrease, degum, dehorn, deplume, and detassel, all recognized by the dictionaries, are good examples of this group. It is significant that many new terms of this kind are coming into use, though not yet found in the dictionaries. Among such new terms, besides "dehull," found in current literature, are debitter, debunk, defat, defruit, deglume, dehusk, delead, delint, delouse, deluster, demouse, deseed, desprout, and detail.

Another large group of words of similar nature is represented by the root with the prefix "un," rather than "de," but also meaning to remove. Good examples are unballast, unglove, unharness, unroof, unsaddle, and unwrap. In another group the removal of an article or a quality is indicated by the suffix "less." Such words as awnless, brainless, harmless, hullless, leafless, stringless, and tasteless are examples.

[1]Report presented at the annual meeting of the Society held in Washington, D. C., Nov. 22, 1928.

In contrast to the many hundreds of words in which the infinitive or the past tense indicates the possession of the article or quality named in the root, there are only some 20 examples in which the infinitive is given in the dictionaries with the meaning "to remove" or "to deprive of" the article or quality named. There may be a few others not noted. These 20 are, respectively, as follows:

| | | | | |
|---|---|---|---|---|
| to bark | to core | to husk | to scale | to skin |
| to bone | to dust | to milk | to scalp | to sprout |
| to brain | to head | to peel | to shell | to stone |
| to bug | to hull | to pit | to shuck | to top |

A study of the definitions given for these 20 infinitives in the Standard and Webster dictionaries shows that 12 of them have the two entirely opposite meanings, namely, "to remove" or "deprive of," and "to add" or "to produce." Only eight, therefore, (bug, hull, husk, milk, peel, pit, scalp, and shuck) are recorded as having only the single meaning of "to remove."

A rather full study of recent agronomic literature has been made to determine the usage of the terms "hulled" and "dehulled." In practically all of the papers dealing with the cereal crops, the word "hulled" was used with the meaning "having the hulls on." In only a few was it used with the opposite meaning, namely, "deprived of hulls," most authors using the term "dehulled" when they wish to carry this meaning. Dr. A. J. Pieters courteously examined a large number of comparable publications dealing with such forage crops as sweet clover, alfalfa, etc. He finds the usage of the term "hulled" in these publications to be almost exactly opposite to that in the ones dealing with the cereal crops. Where the writer does not specifically state which he means, the reader naturally is confused.

It is proposed to extend the study of the literature and to prepare a more comprehensive paper on this subject for publication during the coming year. In the meantime, agronomists are asked to give consideration to the question of whether it is desirable to maintain the use of a few terms in a meaning exactly opposite to the recognized meaning of hundreds of similar terms.

CARLETON R. BALL, *Chairman*
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## SYMPOSIUM ON "TOBACCO RESEARCH"

The papers offered in this group are the result of an attempt to bring together all those members of the Society interested in agronomic research on the tobacco crop, particularly the nutritional phase. It was the opinion of those who made the arrangements that the greatest good might be accomplished by requesting short papers, each dealing with a specific problem or technic and allowing ample time for discussion. The plan worked well and the session was in fact a "Round Table" rather than a "Symposium."—W. L. SLATE, *Leader*.

1. The Chemical Approach to the Study of Problems of Tobacco Fertilization. D. E. Haley, Pennsylvania State College.
2. The Effect of Other Crops on Tobacco. J. P. Jones, Massachusetts Agricultural College.
3. Tobacco as an Indicator Plant in Studying Nutritional Deficiencies of Soils under Greenhouse Conditions. M. F. Morgan, Connecticut Agricultural Experiment Station.
4. Nutritional Problems in Bright Tobacco. E. G. Moss, U. S. Department of Agriculture.
5. Nutritional Deficiency Studies on Tobacco. J. E. McMurtrey, Jr., U. S. Department of Agriculture.
6. A Water Culture Technic for Studies in Tobacco Nutrition. A. B. Beaumont and G. J. Larsinos, Massachusetts Agricultural College.
7. Soil Reaction Studies on the Connecticut Tobacco Crop. P. J. Anderson, Connecticut Agricultural Experiment Station.
8. Some Factors Affecting the Nicotine Content of Tobacco. C. W. Bacon, U. S. Department of Agriculture.

## 1. THE CHEMICAL APPROACH TO THE STUDY OF PROBLEMS OF TOBACCO FERTILIZATION[1]

D. E. HALEY[2]

Of the many factors involved in the production of good-quality cigar-leaf tobacco, the potassium requirement is one of the most important. In order that we may understand more clearly its importance, let us first consider several well-established facts of a chemical or biochemical nature which bear directly or indirectly on this subject, and, furthermore, let us formulate a chemical interpretation for a number of otherwise unexplainable observations which have been noted by a number of workers in their investigation dealing with the relationship of potassium to the plant itself and to the quality of the product.

A knowledge of the condition of potassium as it normally occurs in the soil is of fundamental importance in a study of this kind. A small quantity of this element is usually present in either chemical or physical union with the soil organic matter. A portion of this potassium is readily available for plant growth, but complete availability can only be attained by decomposition of the organic matter. It is necessary, therefore, to pay close attention to the biological conditions of the soil and especially to those factors affecting the number and activities of the organisms which decompose organic matter. Work of the Cornell and other experiment stations has shown that the nutrition of these organisms must be provided for even before that of higher plants. The fact that additions of organic matter lead to a temporary depletion of soil nitrogen certainly emphasizes this point. What is true for nitrogen probably is true for other essential plant nutrients, although the effect may not be so apparent. With this in mind, we should profit from the results of investigations of the factors involved in the depletion of soil nutrients and especially with the factor of crop rotation. Moreover, the preceding crop may have a direct or indirect bearing on the activity of soil micro-organisms, apart from its effect on the available supplies of plant nutrients. There is, for instance, the favorable effect of clover as contrasted with the unfavorable effect of timothy, as shown by the work conducted at Cornell and elsewhere.

[1]Paper read as part of the symposium on "Tobacco Research" at the meeting of the Society held in Washington, D. C., November 23, 1928. Publication authorized by the Director of the Pennsylvania Agricultural Experiment Station as Technical Paper No. 473.

[2]Professor of Soil and Phytochemistry, Pennsylvania State College, State College, Pa.

The bulk of the soil potassium is held in inorganic combinations and is looked upon as being more or less unavailable for plant growth. Considerable quantities of this potassium may, nevertheless, become available for tobacco plants if the proper conditions are maintained. Especially is this true for that portion adsorbed by the inorganic soil colloids. Potassium so combined may be in equilibrium with the potassium dissolved in the soil solution, but the concentration of the latter is usually quite low, although an acid condition increases the amount going into solution. This quantity is directly available for plant nutrition, but for maximum absorption, however, the root-hairs must be in intimate contact with the individual soil particles so that the evolution of carbon dioxide from the plant may lead to the displacement of the adsorbed potassium, hydrogen taking its place in the colloidal complex. This form of potassium is quite satisfactory for nutritional purposes because no harmful acid radical is combined with it. Any factor, therefore, which favors root development will increase the amount of potassium absorbed by the growing plant which, on the whole, is desirable.

Some plants may absorb sufficient quantities of potassium from the soil to supply their needs, but this is not true for tobacco plants on account of their limited root systems. For this reason, therefore, it is necessary to have ample quantities of readily available potassium at their disposal to supply not only their nutritive requirements, but to provide sufficient quantities to insure good burning qualities. From this standpoint, therefore, the question of potash additions should receive careful consideration and in this connection it may be said that as far as work at the Pennsylvania Station is concerned muriate of potash should never be used as a fertilizer for cigar-leaf tobacco.

The addition of the common potash salts to soils relatively high in colloidal matter results in potassium being adsorbed and other adsorbed bases being replaced. The bases which are replaced subsequently combine with the acid radicals of the potash salts. Theoretically, it would appear possible for the acid radicals to be leached out of the soil. Our results show, however, that seasonal differences have no effect upon the quantity of chlorine absorbed by the plants from a given application of muriate of potash. On the other hand, these experiments have shown that sulfur is not absorbed very readily, or at least it does not accumulate in the leaves to any great extent.

Potassium in combination with acid radicals, such as the chloride and sulfate, will not function properly in combustion. Therefore, a wide ratio between potassium and such radicals is extremely important. For this reason, therefore, it would appear that the car-

bonate or nitrate of potash would be more desirable as a fertilizer than either the muriate or sulfate. The effects of carbonate of potash on the reaction of the soil and its physical condition is not desirable. Neither is the over-loading of the plant with readily available nitrogen compounds desirable. If, however, the conditions are such that the nitrogen of nitrate of potash is utilized efficiently by the plants, there results a liberation of potassium for its normal functions in growth and for catalytic activities during combustion.

In our work at the Tobacco Station located at Ephrata, Lancaster County, Pennsylvania, we have used 200 pounds of sulfate of potash per acre, believing that this amount was sufficient for our purpose. Analyses of the 1925 crop, however, showed a potash content of the leaves only slightly in excess of 2%. On the other hand, the lime content ran quite high, approximately 8%. In 1926 the potash and lime content were approximately 3% and 7%, respectively, while in 1927 each of these constituents approximated about 5%.

The quantity of potash in the leaves appeared to be directly proportional to the moisture conditions, while the lime content was inversely proportional. These results lead us to believe that a considerable amount of lime must have been leached out of the soil. Simultaneously a better root development of the plant was obtained resulting in more potash being absorbed. Considerable evidence is now available, however, which shows that the presence of relatively large quantities of active lime compounds in an ordinary soil seriously interferes with the solubility of the potash and its absorption by plants.

The burning qualities of the three crops closely paralleled their potassium content, and especially was this true as to the form in which this element occurred in the leaves. This brings out the question of the relation of potassium to the plant itself. It is thought that it plays a rôle in the synthesis of carbohydrates. In order that it may function in this capacity, however, it must be in a more reactive form than either the chloride or sulfate.

Another of the important rôles of potassium in plant metabolism is to neutralize the acids produced as a result of cell metabolism. Therefore, in order to function properly, it should likewise be in a more reactive form than either the muriate or sulfate. If a plant is properly supplied with potash, sufficient quantities are present for the neutralization of acids and to transport them to older tissues containing higher quantities of calcium where they may be precipitated. If these acids are not removed from the reactive system, the plant does not develop normally and is less resistant to the attacks of

disease organisms. For this reason, any factor leading to an undue production of organic acids, such as heavy applications of nitrate nitrogen, should be avoided because it tends to increase the duties of the potassium present.

We believe that the more potassium found in the leaf in combination with organic acids, especially those containing hydroxy groups, the better the quality of the tobacco. Such tissues are usually of a low acidity which is conducive to good curing and fermentation. Moreover, it is a well-known fact that the catalytic effect of potassium during combustion is greater where it is combined with organic acids than if it were present as the muriate or sulfate.

The relation of potassium to other plant compounds should not be minimized. We recognize, for example, that iron may act as a catalyst during combustion if it is present in a certain form or forms. Moreover, it is also recognized that an alkaline reaction is more desirable for efficient combustion than is an acid reaction. Compare, therefore, the system of potassium chloride—iron chloride with the system potassium citrate—iron citrate. Under which condition would it be possible for both an alkaline reaction to be obtained during combustion and the subsequent precipitation of iron oxides? An additional point, however, must be taken into consideration. Where potassium salts of hydroxy organic acids are present in relatively large amounts, there is afforded an opportunity for iron to enter such a molecule to form a soluble complex. We believe that under such conditions, a better distribution of the iron occurs throughout the tissues. Certainly Hoffer's work shows this to be true. If iron does occur in this form it is precipitated during combustion in a colloidal state thus yielding a maximum surface for catalytic action. Moreover, it is found to possess magnetic properties when precipitated in this way, and as iron is supposed to show maximum catalytic powers when it approaches a mixture containing an equal quantity of $FeO$ and $Fe_2O_3$, especially when an active basic compound is present, this form of iron and potassium is desirable.

In conclusion I wish to say that probably no agricultural plant presents such enormous possibilities for further and more detailed chemical studies than does the tobacco plant.

## 2. THE EFFECT OF OTHER CROPS ON TOBACCO[1]

J. P. Jones[2]

The studies that have been made on the effect of other crops on tobacco group themselves under three general heads, *viz.*, (a) effect of other crops on yield and quality of tobacco, (b) association of brown root-rot with crop effects, and (c) the cause of brown root-rot.

### EFFECT ON YIELD AND QUALITY

In this paper an attempt has been made to evaluate the effects different crops may have on tobacco in different parts of the country where records were available. In doing this the yields obtained with rotations of various sorts have been rated in relation to the yields of tobacco in continuous culture, the later being rated at 100. In this manner it will be possible to observe the relative response of tobacco to the different crops which preceded and to compare directly results from one section of the country with those from another. The results are tabulated in Tables 1 and 2. It should be recognized that while the continuous tobacco, used as a standard of comparison, was grown on the same general field in each instance it was not in all cases as close to the differently treated plats as might be desirable for the drawing of fine distinctions. In addition to the cropping treatments, the tobacco was fertilized in accord with what is good practice in the locality where the experiment was conducted.

The work of the U. S. Department of Agriculture (4)[3] in Maryland, Connecticut, and Massachusetts (5), and that of the Ohio (9), Connecticut (1), and Massachusetts (6, 7) experiment stations has been used in the preparation of these data. Other stations have done work with rotations, but it was impossible from the information given to compare the results with those for tobacco growing in continuous culture. In fact some stations, particularly in the South, seem to have taken it for granted that the value of rotations for tobacco does not need to be proved and hence have omitted continuous culture of tobacco from their rotation comparisons.

### CROPS IN ROTATION

In classifying the data from the different stations the effects of two types of cropping systems were observed, *viz.*, (a) tobacco growing in

[1]Paper read as part of the symposium on "Tobacco Research" at the meeting of the society held in Washington, D. C., November 23, 1928. Contribution No. 92, Massachusetts Agricultural Experiment Station, Amherst, Mass.

[2]Research Professor of Agronomy.

[3]Reference by number is to "Literature Cited," p. 129.

rotation with other crops and (b) tobacco growing every year on the same land with a winter cover crop turned down in the spring.

TABLE 1.—*Relative response of tobacco to the influence of other crops grown in rotation, with continuous tobacco as 100.*

| Tobacco after | Upper Marlboro, Md. | Windsor, Conn. | Whately, Mass. | Amherst, Mass. | Wooster, Ohio |
|---|---|---|---|---|---|
| Tobacco | 100 (1,099)* | 100 (1,069)* | 100 (1,670)* | 100 (1,587)* | 100 (1,023)* |
| Potatoes | 102 | 88 | 73 | 98 | — |
| Corn | 109 | 82 | 20 | 87 | — |
| Wheat | 99 | — | — | — | — |
| Oats | 99 | — | — | — | — |
| Rye | 87 | — | — | — | — |
| Beans | — | 89 | 62 | — | — |
| Tomatoes | — | 96 | 77 | — | — |
| Fallow | — | 91 | 98 | — | — |
| Onions | — | 98 | 80 | 112 | — |
| Timothy hay | — | 95 | 17 | 91 | — |
| Clover hay | — | 99 | 29 | — | — |
| Wheat and crimson clover in 2-year rotation | 88 | — | — | — | — |
| Wheat and cowpeas in 2-year rotation | 105 | — | — | — | — |
| Wheat and red clover in 3-year rotation | 100 | — | — | — | 112 |
| Corn and timothy hay in 3-year rotation | — | — | — | 61 | — |
| Potatoes and onions in 3-year rotation | — | — | — | 84 | — |

*Pounds per acre.

Comparing different sections of the country it is readily apparent from Table 1 that previous crops are more likely to be injurious to tobacco in New England than in either Maryland or Ohio. In none of the three experiments in New England did tobacco do as well following other crops, with the exception of onions at the Massachusetts Station, as it did following itself. If the soil at Massachusetts had been limed sufficiently to grow onions well, it would have been more poorly adapted to tobacco, because liming usually increases injury from brown root-rot. For this reason and because of the discouraging results obtained at Windsor and Whately, onions cannot be considered always a safe crop to precede tobacco.

In Maryland the rotations with rye and with wheat and crimson clover seemed to have the most deleterious effects. Unfortunately, these crops were not grown in connection with the other experiments and cannot be judged for other parts of the country. Tobacco increased in yield in Maryland following corn by about 9%, while in New England it decreased by about 37%. This difference in the effect of corn in the two sections is marked, indicating very different conditions for growth. It should be pointed out that in the yields obtained in the Maryland experiments 1,200 pounds per acre is a high average in contrast with 1,670 pounds for New England. The Ohio yields are about the same as for Maryland. This might indicate that some other limiting factor is operative and the full effects of previous crops cannot manifest themselves.

In New England tobacco yields best following tobacco, next best, in the order mentioned, after fallow, onions, potatoes, and tomatoes. Onions, on the other hand, may do poorly after tobacco, while many other crops do well. Tobacco has also done well after potatoes in Maryland. After corn, timothy hay, and clover, tobacco has done the most poorly under New England conditions. An interesting observation has been made by Johnson and his coworkers (5) in the Whately experiments. They found that the first year following certain crops the maximum reduction in yield was obtained, while in the second year a marked recovery was noted. For example, the first year after corn (1923) tobacco yielded 540 pounds per acre and the second year (1924) 1,100 pounds in contrast with 340 pounds per acre during the 1924 season for tobacco the first year after corn.

The three-year rotations seem to have been satisfactory in Maryland and quite successful in Ohio. The yield of tobacco after wheat and red clover was fully as good as tobacco grown in continuous culture in Maryland and was increased by about 12% in Ohio. Garner and his associates (4) imply that the results with this rotation might be explained on the theory that a tobacco soil needs a rest every so often. In this three-year system the land is disturbed the minimum. On this basis it would appear that long rotations with the least disturbance of the soil would be ideal for tobacco. In a similar rotation at Amherst where tobacco followed corn and timothy hay the yield has been reduced on the average for four years by 39%. The outstanding difference between these two rotations is that at Amherst manure was applied in addition to the fertilizer and the land had to be plowed for corn the second year, thus not providing the same rest for the soil that was allowed in the Maryland rotation.

At Amherst another type commonly spoken of as the money crop rotation has been conducted in comparison with the animal husbandry rotation and has proved much more promising. In the money crop rotation tobacco follows potatoes and onions with no manure as a by-product for the tobacco. The yield of tobacco even without the manure has always been greater than that of the animal husbandry rotation where the tobacco, well fertilized with both manure and fertilizer, followed corn and hay. While better than the animal husbandry rotation, Table 1 shows that tobacco following potatoes and onions was poorer by about 16% than that grown in continuous culture.

Quality has also been recorded for some of the experiments discussed. The records of Garner and his coworkers (4), where tobacco follows wheat and cowpeas, show this cropping system to exert a depressing effect on quality sufficient to offset the increase in yield obtained. Their records show further, that while the yield in the three-year rotation of wheat, red clover, and tobacco was about the same as tobacco grown every year on the same land, the quality was notably superior. In New England the general observation has been that quality is associated with yield. With cropping systems which materially cut the yield of tobacco, reduction in quality has resulted. This has proved particularly true where heavy cuts in yield have been encountered such as after corn and hay.

Looking at the effects crops in rotation have on tobacco as a whole certain facts stand out as follows:

1. To improve yield and quality of tobacco more promising means should be sought than that offered by rotation.

2. Probably the most profitable method of raising tobacco is growing it every year on the same land and fertilizing well.

3. The data here presented, while constituting an interesting agronomic story in themselves, furnish little understanding of the problems involved. The question is, Why should cropping systems so satisfactory with other crops prove so detrimental to tobacco?

4. The severity of the depressing effects of crops preceding tobacco varies with different sections of the country, being most evident in New England.

5. In New England, if rotation is practiced at all, it should be confined to such crops as potatoes, onions, or tomatoes. In Maryland and Ohio the general principle of having a rather long rotation with the land disturbed as little as possible between the tobacco crops should be considered. The question of crops to use in these sections does not seem as important as in New England.

6. A very definite question is presented for explanation in, Why should yields of tobacco be consistently higher in the Connecticut Valley than in other sections of the country? Certainly it is not because of greater native fertility of Connecticut Valley soils. Perhaps rotations are practiced too extensively in other sections.

## COVER CROPS

In recent years experiments have been conducted with cover crops in Maryland (4), Massachusetts (6, 7), and Connecticut (1). The results have been summarized in Table 2 using the same system of relative expression for the responses to different cover crops as that used in Table 1 for rotations. The yield of tobacco grown every year on the same land is rated at 100, and that grown with the different cover crops rated proportionally according to the yields obtained. Eight years' records are considered in the figures for vetch and crimson clover and 12 years' for rye in the Maryland experiments. At Windsor only two years' records have been obtained, while at Amherst the experiments have been conducted for four years.

In the Maryland results vetch is the only cover crop of those tested which is satisfactory and even it failed to produce a return that readily justifies the expense of seeding it. Rye and crimson clover might be considered failures. Rye was also used in the Windsor and Amherst experiments with much more satisfactory results, but produced no increase in yield. Vetch seemed to do about as well at Windsor as in Maryland. In New England, with the exception of timothy in the Amherst experiments, cover crops have had little influence on yield. Timothy at Amherst three years out of four has significantly decreased the yield of tobacco. These were dry years but last season (1927), when rain was more plentiful, differences due to the timothy cover crop were insignificant.

TABLE 2.—*Relative response of tobacco to the influence of different cover crops, with continuous tobacco as 100.*

| Cover crop | Upper Marboro, Md. | Windsor, Conn. | Amherst, Mass. |
|---|---|---|---|
| No-cover | 100 | 100 | 100 |
| Timothy | — | 99 | 90 |
| Rye | 69 | 101 | 99 |
| Redtop | — | 95 | 101 |
| Vetch | 104 | 100 | — |
| Crimson clover | 89 | — | — |
| Barley | — | 106 | — |
| Oats | — | 102 | — |
| Alfalfa | — | 98 | — |
| Wheat | — | 100 | — |

The results show a marked consistency in the failure of all cover crops so far tested to produce a notable increase in either yield or quality. In some instances timothy as a cover crop has actually depressed yield and quality. These experiments should be conducted longer before concluding that soil improving programs for tobacco that involve the use of cover crops are useless. Nevertheless, the results obtained to date support the recommendation to the grower that cover crops have very little fertility value for tobacco and that he can better save his money by not investing in them. The only apparent justification for a cover crop seems to be to protect certain types of soil which are subject to serious erosion by wind or water.

ASSOCIATION OF BROWN ROOT-ROT

Since in the foregoing discussion it appears evident that previous crops may exert a deleterious influence on tobacco, the question naturally arises, What is the cause of these depressing effects? Several investigators have been giving attention to this question. In studying the roots of plants grown in the Whately and Windsor experiments, Johnson and his associates (5) found that brown root-rot was much more severe after timothy, corn, and clover than after some other crops. This was particularly true of the Whately experiments where the soil was known to be infested with brown root-rot. It was less true at Windsor where the soil was relatively free of brown root-rot and the effect of previous crops much less depressing. Johnson and his coworkers (5) also made observations on the soil and the experiments in Maryland and consider brown root-rot to be a factor in the results obtained. It might be inferred from some of the observations of Johnson and his associates (5) that brown root-rot is more severe in New England than in other sections of the country. This might explain in part the greater decrease in yields resulting from previous crops in the Connecticut Valley than in other sections.

In the Massachusetts experiments the writer (7) has kept definite records on the relative severity of brown root-rot for the different cropping systems. The results show that the percentage of plants showing brown root-rot varies with the cropping systems. Tobacco growing in continuous culture without a cover crop showed 18% brown root-rot, but when a timothy cover crop was used the brown root-rot was found on 73% of the plants. In the animal husbandry rotation with tobacco following corn and timothy hay, brown root-rot occurred on 87% of the plants. Tobacco grown after potatoes, corn, and hay showed 37, 40, and 44% of brown root-rot, respective-

ly. After onions and tobacco only 3 and 17%, respectively, of brown root-rot were noted. Referring to Tables 1 and 2, it will be seen that these observations on brown root-rot correlate with the yield records for the Massachusetts experiments. The largest yields were obtained after onions and tobacco where brown root-rot was at a minimum, the smallest yield in the three-year animal husbandry rotation where brown root-rot was most severe.

It would appear from the close association noted by different workers between brown root-rot and crop effects that an explanation of brown root-rot would go a long way toward an understanding of some of the influences preceding crops have on tobacco. Two views have been held, neither of which can be entirely supported by experimental evidence. According to the first of these, brown root-rot is a disease due to a specific organism. The second view presents brown root-rot as due to malnutrition, possibly caused by a deficiency in some plant nutrient or by soil toxins. Work has been reported along both lines.

### SPECIFIC ORGANISM

Johnson and his coworkers (5) have probably done most on the brown root-rot problem from the disease standpoint. They claim that certain evidence supports very definitely the parasitic hypothesis, while other evidence just as definitely refutes it. They describe brown root-rot as a condition on the roots of tobacco and other plants characterized by a brown discoloration and decay of the root system. Some of the characteristics which these writers think typical of a parasitic disease are as follows:

1. It is destroyed in the soil by sterilizing with steam or formaldehyde.

2. Brown root-rot soil when mixed with soil free of brown root-rot will result in the production of the disease, the severity being roughly proportional to the quantity of the brown root-rot soil added.

3. Diseased roots washed free of soil will cause brown root-rot when mixed with a soil known not to contain the disease.

4. The behavior of the disease on plants grown at different soil temperatures is apparently more closely related to biological than to chemical activity.

In spite of the various indications that an organism was concerned in the brown root-rot injuries none has been found. Johnson and his associates (5) claim that, although Fusarium, Rhizoctonia, Actinomyces, and bacteria were found on the tissues of affected roots, none were capable of producing brown root-rot in inoculation

experiments. He further states that there is still the possibility of an unknown parasite being concerned.

## MALNUTRITION

Considering brown root-rot from the standpoint of a nutritional disturbance the following supporting observations have been made:

1. Brown root-rot can be driven from the soil by air drying either in the presence or absence of sunlight, indicating that no organism is concerned but suggesting the possibility of a volatile toxin.

2. In the field, brown root-rot has been observed to fall along very definite lines, usually according to previous treatment, just as is frequently found with nutritional effects. There is most often not the distribution expected of an infectious disease.

3. Burgess (2) has linked crop effects with toxic aluminum. Since brown root-rot is often associated with crop effects, Why may not a toxin such as aluminum be concerned?

4. Turning down crop residues of various sorts has been shown to have a depressing effect on the available nitrogen. Brown root-rot brought on by turning under crop residues may be but a manifestation of deficient nitrogen.

5. In the decomposition of the crop residues which seem capable of inducing brown root-rot, organic toxins may be liberated. These may vary in their nature and thus account for some of the variations in the prevalence of brown root-rot.

In line with the malnutrition view of brown root-rot Doran (3) has reported some interesting results. He shows that the influence of timothy residues depends upon the age of decomposition. Timothy infusions up to three weeks old had no appreciable effect on the growth of tobacco. Those five to eight weeks old reduced the growth by about 86%. On the other hand, with timothy infusions nine to ten weeks old the yield was reduced only about 30%. Brown root-rot was found to correlate with the growth obtained with the different aged infusions, being practically absent for those one to three weeks old, very severe for those five to seven weeks old, and only slight on those plants treated with the nine- and ten-week-old infusions. These results, together with those of Johnson and his associates (5) at Whately and observations made by the writer, show the transitory nature of brown root-rot. They also indicate that the brown root-rot may be due to a volatile toxic decomposition product of crop residues.

The findings of numerous investigators on the depressing influence of carbonaceous residues on available nitrogen led the writer

to investigate the soil nitrates as affected by different crop residues. Nitrate determinations were made weekly during the growing season of tobacco, preceded by different crops. The results are shown in Table 3.

TABLE 3.—*Nitrate accumulation in p.p.m. of $NO_3$ on a dry soil basis as influenced by cropping systems.*

| Treatments | June 9 | June 17 | June 24 | July 1 | July 8 | July 15 | July 22 | July 29 | Aug. 5 | Σ | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *Continuous Tobacco* | | | | | | | | | | | |
| Fertilizer only | 161 | 341 | 289 | 405 | 673 | 364 | 325 | 292 | 179 | 3,029 | 337 |
| Fertilizer and manure | 341 | 522 | 314 | 397 | 797 | 375 | 373 | 334 | 225 | 3,678 | 409 |
| Fertilizer and timothy cover crop | 166 | 254 | 264 | 369 | 555 | 313 | 340 | 241 | 197 | 2,699 | 300 |
| Fertilizer and rye cover crop | 154 | 284 | 281 | 349 | 611 | 308 | 390 | 263 | 149 | 2,789 | 310 |
| Fertilizer and redtop cover crop | 155 | 226 | 273 | 380 | 609 | 327 | 361 | 331 | 242 | 2,904 | 323 |
| *Rotation Tobacco* | | | | | | | | | | | |
| Animal husbandry rotation | 107 | 148 | 196 | 345 | 389 | 283 | 214 | 235 | 185 | 2,102 | 234 |
| Money crop rotation | 244 | 315 | 342 | 386 | 602 | 440 | 439 | 247 | 136 | 3,151 | 350 |

It is evident from the results that slight depressions in nitrates in the soil have accompanied the turning under of crop residues. The greatest depression occurred in the animal husbandry rotation where the tobacco followed corn and timothy hay. Timothy cover crop showed the next greatest nitrate depression with rye next and then redtop. Continuous tobacco without a cover crop showed a slightly less nitrate accumulation than that in the money crop rotation, tobacco following potatoes and onions. The nitrates ran highest in the plats growing tobacco every year without a cover crop but with manure added. In general these observations agree quite well with those of other investigators showing a depression in nitrates due to the turning under of carbonaceous residues.

It is also interesting to note that brown root-rot and yields followed rather closely these results with nitrates. In the animal husbandry rotation where nitrates were depressed to the greatest extent a yield of 860 pounds per acre of tobacco, with 100% brown root-rot, was obtained. On the manure plats, where nitrates ran highest, 1,763 pounds per acre of tobacco were produced with only 17% of brown root-rot. The timothy cover crop plats, showing a depression of

nitrates next greatest to that noted in the animal husbandry rotation, yielded 1,512 pounds of tobacco per acre with about 69% brown root-rot, as contrasted with 1,655 pounds of tobacco and only 5% brown root-rot on the continuous tobacco plats with no cover crop. An exception occurs in the case of the money crop rotation where there was no depression in nitrates yet the yield of tobacco was only 1,426 pounds per acre with 50% of brown root-rot. It is not fair to consider the rye and redtop in these comparisons since it was the first year they had been used on the plats.

One discrepancy appears which makes it impossible to explain brown root-rot on the basis of nitrogen deficiency resulting from the incorporation of carbonaceous residues in the soil. Most other investigators have worked with lower levels of nitrates and consequently the nitrate depressions they have found on turning under crop residues might easily have rendered nitrogen deficient. In the experiments discussed here the animal husbandry rotation plats, on which nitrates were lowest during the season, ran from 107 at the beginning to 389 p.p.m. at the peak of the growing season. Surely nitrates could not be deficient when they are present in such abundance. Besides, experience on other plats has shown as much as 95% larger yields to be obtained on a much lower nitrate level.

Work has been started at the Massachusetts Experiment Station to determine if certain inorganic toxins may not possibly be the cause of brown root-rot. To date attention has been given particularly to aluminum. Aluminum has been found by Burgess (2) to be especially harmful on acid soils and its toxicity seriously influenced by crops. The Connecticut Valley soils on which tobacco is grown are generally very acid and this is just the condition that favors aluminum toxicity. On certain soils where tobacco has been noted as presenting a stunted appearance heavy applications of superphosphate have remedied the situation completely. Superphosphate is a recognized corrective for aluminum toxicity. These responses to superphosphate and the very acid soil on which tobacco grows make the possibility of aluminum being a factor in brown root-rot seem very plausible.

In Table 4 are presented some results of water culture experiments where different amounts of aluminum have been superimposed upon nutrient media. The cultures were maintained at a pH of approximately 4.0. Crone's nutrient solution was used. In 1927 various amounts of aluminum sulfate were added to the solution. In 1928 the aluminum sulfate was alternated with the phosphate treatments

in the manner described by McLean and Gilbert (8) to avoid the precipitation of the aluminum which is likely to occur in the presence of phosphates. This was also thought to give a more accurate picture of the aluminum toxicity. It was apparent that in water cultures 38 p.p.m. of $Al_2O_3$ is toxic to tobacco. Seventy-six and 153 p.p.m. of $Al_2O_3$ seemed to be more toxic where the aluminum was added directly to the full nutrient solution than where it alternated with the phosphates.

TABLE 4.—*Growth of Havana seed tobacco in water culture as influenced by different amounts of aluminum.*

| $Al_2O_3$ in p.p.m. in nutrient solution | Dry weight per plant in grams, 1927* Tops | 1927* Roots | 1928† Tops | 1928† Roots |
|---|---|---|---|---|
| 0 | 6.57 | 0.82 | 9.92 | 1.36 |
| 2.37 | 5.80 | 0.69 | 8.10 | 1.36 |
| 4.74 | 5.25 | 0.62 | 8.26 | 1.35 |
| 9.56 | 5.44 | 0.73 | 9.35 | 1.36 |
| 19.13 | 4.90 | 0.65 | 10.80 | 1.83 |
| 38.26 | 3.59 | 0.44 | 4.85 | 0.98 |
| 76.52 | 0.57 | 0.07 | 4.55 | 1.03 |
| 153.04 | 0.32 | 0.07 | 2.29 | 0.58 |

*Aluminum sulfate superimposed on the Crone's nutrient solution.

†Alternation system employed, aluminum sulfate alternating every 3½ days with the phosphates. This was done to avoid precipitation of aluminum.

Accompanying these toxic effects of aluminum as manifested by decreased growth there were always brown roots similar to those observed in the field as brown root-rot. The tobacco plant apparently is quite sensitive to aluminum injury in water culture. This relationship of aluminum needs to be studied further.

It is evident from the observations noted here and those made under a number of other situations that brown root-rot may be caused by a number of conditions. Before it can be definitely shown to be the cause of the various crop effects, some method must be evolved of identifying the brown root-rots produced under the various conditions with that associated with the effect of different crops on tobacco in the field. The evidence thus far is only suggestive of the factors involved in causing brown root-rot. The whole problem of crop effects, therefore, still remains very obscure and it is the opinion of the writer that it will continue to remain so until brown root-rot is better understood. A solution of the brown root-rot problem is also believed to be a vital step in solving numerous other problems which are of very serious concern to the tobacco grower.

## SUMMARY

The effects of other crops on tobacco are discussed in the light of the reports by the U. S. Department of Agriculture on its work done

in Maryland, Connecticut, and Massachusetts and of those by the Ohio, Connecticut, and Massachusetts experiment stations. Certain crops in rotation were observed to exert depressing effects on tobacco, while others seemed to be indifferent. Those producing notable increases in yield and quality were quite rare. The rotation of tobacco, wheat, and red clover produced very satisfactory returns in Maryland and Ohio. A similar rotation of tobacco, corn, and timothy or clover hay seriously decreased the yield and quality of the tobacco in Massachusetts. The results show a lack of consistency in the way different crops affect tobacco in different sections.

The results with cover crops are quite similar to those where different crops are grown in rotation. In some cases decreases in yield accompanied the use of cover crops, in others the yield was unaffected. In no case was there a return from cover crops that would justify their use.

Crop effects have been found to be associated with brown root-rot. In New England particularly, the most serious injury from previous crops has accompanied severe brown root-rot. Where brown root-rot was not severe, crop effects have been less marked.

The cause of brown root-rot is still recorded as unknown. Results to date indicate that it probably is not a disease caused by a specific organism. Timothy infusions and aluminum have been found to induce brown root-rot. It is anticipated that a better understanding of brown root-rot as it manifests itself under different conditions will greatly assist in the explanation of crop effects.

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# 3. TOBACCO AS AN INDICATOR PLANT IN STUDYING NUTRITIONAL DEFICIENCIES OF SOILS UNDER GREENHOUSE CONDITIONS[1]

M. F. Morgan[2]

The study of soils in greenhouse pots gives opportunities of controlled conditions and critical observation that are impossible in the field. In foreign countries, notably Germany, much attention is given to this subject, as indicated by the extensive use of Mitscherlich pots. A serious problem in this type of work is the choice of a suitable plant to reveal the soil differences under investigation. Most of the crops ordinarily grown in the field are more or less unsatisfactory. Some require too much space. Plant variability eliminates most field crops. Greenhouse insects and diseases are very troublesome on many vegetable crops which are sensitive to nutritional deficiences in the soil. Some field crops are not sufficiently responsive to fertilizer treatment to show the large differences which are necessary to give significant results under greenhouse conditions.

## PLAN OF INVESTIGATION

The Connecticut Experiment Station began a study of the fertilizer requirements of several important soil types of the state in the winter of 1925. Alfalfa, corn, lettuce, carrots, beets, onions, buckwheat, barley, and tobacco have been grown in greenhouse pots (2-gallon glazed water jars with drainage hole at the bottom on the side) on soils treated with lime, nitrogen, phosphorus, and potassium in various combinations. Tobacco has proved to be the most satisfactory of any of the crops grown.

The general technic is as follows: The surface soil is collected from a field which has not been limed or fertilized for several years. Opportunities for obtaining such a condition are found in fields which have been in grass sod for many years, and have become reduced to the normal productive level of the soil, unsupplemented by fertilizer or lime treatment. The soil is screened and mixed thoroughly, and a series of 16 pots are filled with soil. Precipitated chalk is added to all limed pots at rates equal to 1½ times the Jones limestone requirement. The fertilizer treatments are added in solution. Nitrogen is applied as urea, equivalent to 120 pounds per acre. Phosphorus is added as orthophosphoric acid (85%) equivalent to 1,000 pounds

[1]Paper read as part of the symposium on "Tobacco Research" at the meeting of the society held in Washington, D. C., November 23, 1928.

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of 16% superphosphate per acre. Potassium as potassium acetate equivalent to 240 pounds of muriate of potash per acre is applied. The moisture content is made up to optimum, and the pots are planted with Turkish tobacco seedlings of uniform size and showing about five leaves, one plant per pot. Plants which develop abnormally during the first two or three weeks are reset. Very uniform duplicates are obtained in practically all cases.

The crop is mature on all complete fertilizer pots in about two and a half months. Fig. 1 shows a typical series of one of each of the duplicate treatments at this time. Two crops of tobacco on each pot were grown in 1928.

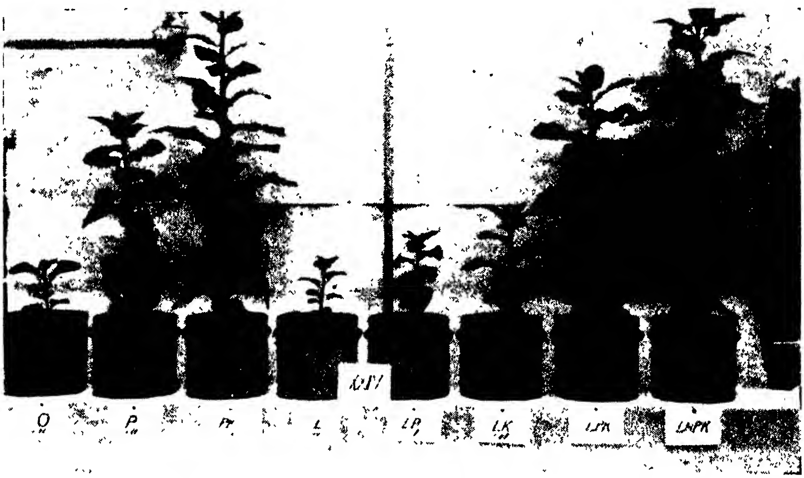



FIG. 1.—Typical series of pots in greenhouse soil studies with Turkish tobacco. All pots marked +N received nitrogen as urea to second crop only. On both first and second crops the treatments were as follows: P = phosphorus as $H_3PO_4$; PK = phosphorus and potassium as potassium acetate; L = lime as $CaCO_3$; LP = lime and phosphorus; LK = lime and potassium; LPK = lime, phosphorus, and potassium; and LNPK = lime, nitrogen as urea, phosphorus, and potassium.

## RESULTS

Tobacco under these conditions showed significant differences associated with the omission of one or more nutrient elements, both in total yield and character of growth. No trouble from insects or diseases was experienced.

Most of the 24 different soils on which tobacco was grown showed response to every treatment except lime.

Characteristic symptoms of nitrogen deficiency were in evidence on all soils to some degree. This was shown by the marked yellowing of

the leaves successively from the base to about one-third the distance to the top, and the subsequent premature dying of some of the lowest leaves, as shown on the "No N" pot in Fig. 2. Total nitrogen content of the soils ranged from 1,550 to 9,850 pounds per 2,000,000, yet even under conditions of more active humus decomposition existing in the greenhouse these soils were unable to meet the nitrogen requirements of the crop. There was no correlation between total nitrogen content and response to nitrogen.

"Frenching" was observed on a number of plants under varied soils and treatment, but was not confined to plants which showed any other symptoms of nitrogen deficiency, or to treatments where nitrogen was omitted from the fertilizer. This is of special interest in relation to the recent work of Valleau and Johnson[3] who have diagnosed "Frenching" as a nitrogen-deficiency disease.

Crops without phosphorus as compared with those with phosphorus ranged from 4.7 to 97.56%. Seven soils yielding less than a 20% crop without phosphorus in the LNK pots showed a habit of growth as illustrated on the "No P" pot in Fig. 2. The height was small in relation to the leaf spread, the leaves were flat, velvety, and failed to show any bulging between the veins such as is noted on normal plants. The color was usually abnormally dark green. No mottling or dying of any portion of the leaf tissue was in evidence.

There was no correlation between response to phosphorus and total phosphorus content of the soil, which ranged from 612 to 2,780 pounds per 2,000,000. There was a striking correlation between phosphorus response and the soil phosphorus soluble in 0.01 N sulfuric acid as determined by an adaptation of the coereleomolybdate method described by Atkins,[4] in use at this laboratory. This is shown graphically in Fig. 3.

Potassium produced a very significant increase in yield on all but two of the soils, both of which had previously failed to show gains from potassium on alfalfa, lettuce, and beets. These soils are no higher in total potassium than the average of the other soils (about 30,000 pounds per 2,000,000). Studies of exchange potassium on all the soils are in progress, but the data are not yet complete. These two soils are both associated with the same geologic formation, a micaceous schist high in biotite and hornblende.

[3]VALLEAU, W. D., and JOHNSON, E. M. Tobacco Frenching—a nitrogen deficiency disease. Ky. Agr. Exp. Sta. Bul. 281. 1927.

[4]ATKINS, W. R. G. The rapid determination of available phosphate in soil by the coereleomolybdate reaction of Denige's. Jour. Agr. Sci., 14:192–197. 1924.


Fig. 2.—Turkish tobacco grown in pots with various nutrients in deficiency, showing characteristic physiological effects.

The characteristic symptoms of potash hunger as described by Moss, et al[5] and shown on the "No K" pot in Fig. 2 were observed on all but one of the other soils. The outer portions of the leaves were turned down and yellowed and in extreme cases the tissue died in irregular patches, especially on the lower leaves. The curled appearance of the leaf is the most striking symptom. The symptoms

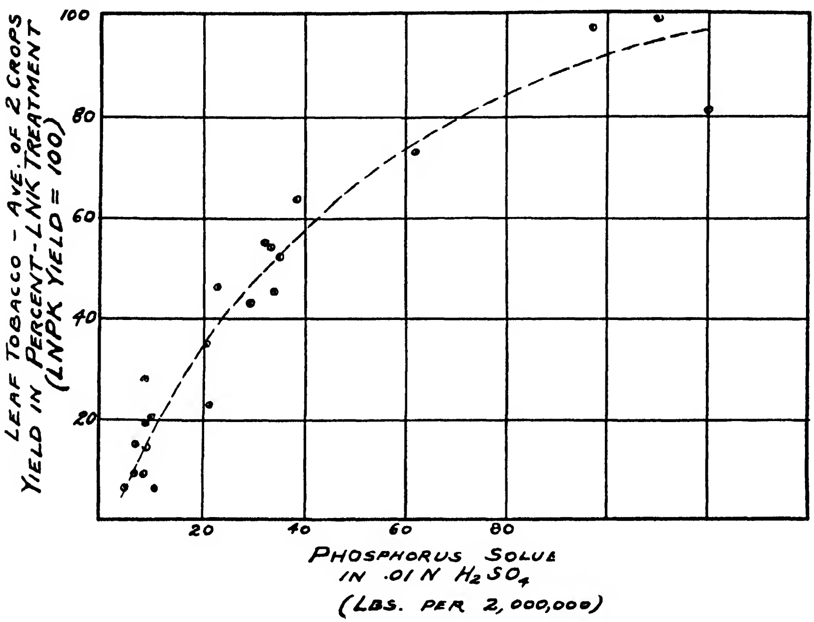



FIG. 3.—Relationship of percentage yield of tobacco without phosphorus to soil phosphorus soluble in 0.01 N sulfuric acid on 24 Connecticut soils.

were much more extreme on limed pots without potassium than on corresponding unlimed pots, except on a soil derived from a limestone formation and which was not acid. It is believed that applications of $CaCO_3$ to acid soils under the conditions of this experiment have decreased the availability of potassium to tobacco, which is in accord with Haley's findings as presented in this symposium.[6]

Lime has produced no significant increase in yield over complete fertilizer treatment except on soils showing pH values of 4.7 pH or below on unlimed pots. Four soils at a pH below 4.2 showed striking responses to lime. Two of these soils in particular exhibited peculiar physiological symptoms. One of them, at a pH of 4.01 on the NPK

[5]Moss, E. G., McMurtrey, J. E., Jr., Lunn, W. M., and Carr, J. M. Fertilizer tests with flue-cured tobacco. U. S. D. A. Tech. Bul. 12. 1927.

[6]See pages 114 to 117.

pots, is shown in Fig. 2 ("No L"). The leaves are wrinkled and distorted in certain localized areas where small spots of tissue turn brown and finally fall out. There is a slight "marbling" of the lower leaves. This soil was very high in aluminum soluble in 0.5 N acetic acid (666 pounds per 2,000,000), although not abnormally high in soluble manganese with the same solvent (58 pounds per 2,000,000). The other soil at about the same acidity (3.96) on the NPK pots prior to the growth of the first crop of tobacco showed a somewhat different appearance. The leaves were strongly mottled over the entire plant, including the leaves which are just opened. Many small brown spots of tissue appeared later where the mottling was not pronounced. The plant was not greatly stunted in size.

The second crop on this soil showed no abnormality on the NPK pots. It was found that the pH had changed to 4.8 pH. The manganese soluble in 0.5 N acetic acid was 816 pounds per 2,000,000 during the growth of the first crop, and had become reduced to 32 pounds per 2,000,000 after the second crop. The soluble aluminum content was somewhat lower than the other soil, although relatively high (322 pounds per 2,000,000), and was practically unchanged after the second crop.

There was no evidence of magnesium-deficiency symptoms as described by Moss, et al[7] on any of the soils, in spite of the fact that no magnesium was applied in any fertilizer combination, and the lime was in the form of pure calcium carbonate. The soils ranged in total magnesium content from 4,196 to 32,672 pounds per 2,000,000. Under the conditions of these experiments, with no leaching of soluble materials from the soil, there was apparently a sufficient amount of magnesium available to the plant to prevent any abnormal physiological effects from this cause.

## SUMMARY

Tobacco (Turkish) has been used with very successful results as an indicator plant to show the fertilizer response of soils under greenhouse conditions.

A deficiency in available supply of a nutrient element is evidenced by significant yield reduction and physiological characteristics of tobacco grown on soils unfertilized with that particular element.

No correlation between response and total amounts of nitrogen, phosphorus, or potassium was observed on any of the 24 different soil types under investigation, but a good correlation existed between phosphorus response and amounts of soil phosphorus soluble in 0.01 N sulfuric acid as determined by the coereleomolybdate method.

[7]*Loc. cit.*

Potassium availability was apparently reduced by liming under the conditions of these experiments.

Lime had no beneficial effect except on soils at pH values below 4.8 pH. On soils below 4.2 pH abnormal plants were produced, and the injurious effects of this degree of acidity may be associated with toxicity of soluble aluminum or manganese, or both.

Data given in this paper are incidental to the discussion and final conclusions should not be attempted until the investigations are concluded.

## 4. NUTRITIONAL PROBLEMS OF BRIGHT TOBACCO[1]

E. G. Moss[2]

In order better to interpret some of the nutritional problems of bright tobacco, it is necessary to consider briefly the purpose for which this tobacco is grown and the soils best adapted to its production. It is estimated that more than 95% of this type of tobacco is used for cigarette, pipe, and chewing purposes which require a tobacco low in nitrogenous and ash constituents and high in sugar and other carbohydrates. One of the most important characteristics of this tobacco is its bright color, which ranges from a mahogany to an orange and lemon, with the lighter colors predominating and being in greater demand. Tobacco of the other types is light brown to very dark in color and, with the exception of the dark-fired, has a thinner leaf.

The physical and chemical properties of the soil are of prime importance in the successful production of bright tobacco. A heavy red soil regardless of its state of fertility will not produce a bright tobacco that will meet the trade requirements. The light soils of a sandy or a sandy loam character are best adapted to its growth, producing a tobacco with bright color, good aroma, and low in nitrogenous constituents. Typical among sandy soils are those of the Granville, Durham, Cecil, and Norfolk series. Obviously the mechanical analysis (Table 1) is of prime importance in determining the adaptability of a soil for production of bright tobacco.

Again, chemical analyses (Table 2) show that on an average these soils are very low in plant nutrients, particularly nitrogen, phosphorous, calcium, and magnesium. While some of the soils are high in potash, it is not readily available.

TABLE 1.—*Average mechanical analyses of the surface soil of typical flue-cured tobacco soils.*

| Soil series and type | Fine gravel % | Coarse sand % | Medium sand % | Fine sand % | Very fine sand % | Silt % | Clay % |
|---|---|---|---|---|---|---|---|
| Granville coarse sandy loam | 15.3 | 23.9 | 10.4 | 14.5 | 8.1 | 19.2 | 8.0 |
| Durham coarse sandy loam | 12.9 | 18.1 | 12.4 | 23.2 | 8.2 | 19.2 | 5.8 |
| Cecil sandy loam.......... | 5.3 | 16.7 | 10.2 | 24.2 | 11.2 | 23.6 | 8.5 |
| Norfolk sandy loam....... | 2.5 | 17.3 | 15.4 | 19.0 | 6.3 | 29.5 | 9.8 |

[1]Paper read as part of the symposium on "Tobacco Research" at the meeting of the Society held in Washington, D. C., November 23, 1928.

[2]Senior Agronomist, Office of Tobacco and Plant Nutrition, Bureau of Plant Industry, U. S. Dept. of Agriculture, and Assistant Director, Tobacco Branch Station, North Carolina Department of Agriculture, Oxford, N. Car.

TABLE 2.—*Average chemical analyses of typical flue-cured tobacco soils.*

| Soil series | Pounds of total plant food constituents per acre in the surface soil to depth of 6⅔ inches | | | | |
|---|---|---|---|---|---|
| | Nitrogen | Phosphoric acid | Potash | Lime, CaO | Magnesia, MgO |
| Granville Series: | | | | | |
| Coarse sandy loam | | | | | |
| Fine sandy loam | | | | | |
| Sandy loam | 625 | 899 | 15,499 | 2,444 | 6,558 |
| Durham Series: | | | | | |
| Coarse sandy loam | | | | | |
| Fine sandy loam | | | | | |
| Sandy loam | 635 | 802 | 13,281 | 7,706 | 1,618 |
| Cecil Sandy Loam | 770 | 546 | 45,036 | 3,100 | 5,459 |
| Norfolk Series: | | | | | |
| Coarse sandy loam | | | | | |
| Fine sandy loam | | | | | |
| Sandy loam | 618 | 529 | 7,717 | 5,317 | 1,800 |

The averages of the total plant food constituents per acre for 6⅔ inches of surface soil of the four major bright tobacco soil series are as follows:

| | | |
|---|---|---|
| Granville Series | Nitrogen | 625 pounds |
| | $P_2O_5$ | 899 pounds |
| | $K_2O$ | 15,499 pounds |
| | CaO | 2,444 pounds |
| | MgO | 6,558 pounds |
| Durham Series | Nitrogen | 635 pounds |
| | $P_2O_5$ | 802 pounds |
| | $K_2O$ | 13,281 pounds |
| | CaO | 7,706 pounds |
| | MgO | 1,618 pounds |
| Cecil Sandy Loam | Nitrogen | 770 pounds |
| | $P_2O_5$ | 546 pounds |
| | $K_2O$ | 45,036 pounds |
| | CaO | 3,100 pounds |
| | MgO | 5,459 pounds |
| Norfolk Series | Nitrogen | 618 pounds |
| | $P_2O_5$ | 529 pounds |
| | $K_2O$ | 7,717 pounds |
| | CaO | 5,317 pounds |
| | MgO | 1,800 pounds |

It is interesting to note the uniformly low nitrogen and phosphorus contents of these soils, also the relatively high potash content of all except the Norfolk series. The Cecil sandy loam with an average total potash content of 45,036 pounds per acre has practically three times that of the Granville, three and one-half times that of the Durham, and six times the Norfolk. The heaviest tobacco

of the bright or flue-cured type is grown on the Cecil sandy loam soils. On the other hand, tobacco with the brightest color is grown on the Norfolk series. The intermediate is grown on the Granville and Durham series. Tobacco grown on the Granville and Durham soil types is considered of high quality from the standpoint of combustibility, aroma, texture, and color.

With these brief observations on the chemical constituents of the four major tobacco soils of the bright type, it is of interest to consider some of the experimental findings as to the effect the individual plant nutrients have on this tobacco. First of all, the relation of the total available nitrogen to the quality of the leaf is very sharply drawn, and a limited supply has the effect of producing a leaf well adapted to the manufacture of a light-colored cigarette. On the other hand, too much nitrogen will produce a rough coarse leaf with large fibres and dark color, which injures the quality of the leaf.

Farm practice and experimental data both make it apparent that between 20 and 30 pounds of nitrogen per acre applied in commercial fertilizers is about the maximum that can be used on the Cecil soils. On the lighter phase of the Norfolk series double this amount, and 30 to 40 pounds per acre on the Granville and Durham series have been used with good results. When applications of available nitrogen much in excess of the above amounts are used, a tobacco high in nitrogenous constituents and dark in color is produced which is undersirable for cigarette purposes. This is in sharp contrast with cigar tobacco production practice where 5 to 10 times as much nitrogen is used.

The sources of the nitrogen supply seem to play a more or less important part in the quality of the cured leaf, although there is some difference of opinion on the subject. It is desirable, therefore, that at least 50% of the nitrogen be derived from the organics of a vegetable or animal origin.

In the production of bright tobacco potash is one of the most important of all the plant nutrients and a liberal use of it is highly desirable. Although the principal tobacco soils seem to be well supplied with total potash, it is not available in quantities sufficient to meet the requirements of the plant, and for that reason potash in a quickly available form has to be supplied. The absence of potash in this form produces a tobacco low in sugar content, and in addition, results in physiological disorders of the plant, making the leaf almost worthless for commercial purposes. Potash hunger has been observed in a few cases when as much as 50 to 60 pounds of $K_2O$ per acre had been applied. Such cases as this occur most frequently on

tobacco that has made an abnormally large leaf growth and it is not severe enough to cause the splotching and breaking down of the leaf tissue which happens when smaller quantities of potash are used.

The Norfolk soils, being more deficient in potash than the others, require a more liberal application under the tobacco. From 40 to 60 pounds per acre is generally used, although 60 to 80 pounds would be profitable in a number of cases. On the Cecil soils about half of this amount seems to be sufficient, while 40 to 60 pounds appear to be about the maximum requirement on the Granville and Durham series.

The source of potash should be given more attention than it has received in the past. It is recognized that muriate will often produce a tobacco with a larger yield and frequently with increased market value but with a poorer burn. The chlorine content of the leaf increases with the increase of chlorine supplied as a plant nutrient, with a more or less corresponding decrease in the sulfur content. In addition to these changes, which are detrimental to the quality of the leaf, an excess of chlorine retards the growth of the plant in its early stages and produces a thick, brittle leaf which is never entirely overcome during the growth of the plant. On the other hand, a small amount of chlorine, possibly not over 20 to 25 pounds per acre, is advantageous to the growth of the plant without any apparent injury to the combustibility of the cured leaf. In addition a small amount of chlorine seems to improve the elasticity and texture of the leaf. For these reasons it is recommended that a fertilizer for bright tobacco shall contain a maximum of 2% chlorine. From one-half to two-thirds of the total potash, depending upon the percentage of potash in the mixture, should therefore be derived from the sulfate of potash or sulfate of potash-magnesia, or both.

The available data on the magnesia content of the soil types under consideration are not so complete as for the other constituents, however magnesia hunger or so-called "sand drown" is more noticeable in field observations on the Durham soils than on the Granville series. Reference to the above analyses of these soil types shows that the Durham series contain on an average only 1,618 pounds of MgO per acre; and the Granville 6,558 pounds, which closely conforms with experimental data and field observations. There seems to be no doubt that this deficiency can be corrected by the addition of MgO in some readily available form. The Norfolk soils and the Cecil sandy loam also have shown deficiencies in magnesia. This nutritional deficiency has caused considerable monetary loss to the tobacco growers in the bright belt.

The phosphorus, calcium, and sulfur requirements are not of special importance at the present time, considered from a practical standpoint, since every grower of bright tobacco uses sufficient superphosphate to supply the normal requirements for these three elements.

The special method of curing with heat applied to bright tobacco is of interest from a physiological standpoint in that the process is hastened in such way as to insure a light color and at the same time prevent the great decrease or disappearance of sugar and starch which occurs in most other methods of curing.

# 5. NUTRITIONAL DEFICIENCY STUDIES ON TOBACCO[1]

J. E. McMURTREY, JR.[2]

## INTRODUCTION

It is important to know the symptoms manifested by the plant when the medium in which it is growing is deficient in one or more elements essential to its proper development. It is possible by this method to use the plant as the indicator of its own nutritional requirements. The tobacco plant, because of its large leaf area which shows definite growth responses, is an excellent plant to use in such studies. When the symptoms are known it is usually easy to correct the trouble in the field by using the proper fertilizers, thus improving the quantity and quality of the product. In some instances the first manifestation may be nothing more definite than decreased growth, but usually careful examination of the plant will disclose well-defined symptoms of malnutrition. It is often difficult in the field to determine the exact element or elements deficient because there are so many factors involved which are not under control and it is often necessary to check observations in the field with water cultures and pot tests in the greenhouse.

The limited time does not permit a discussion of all the elements known to be necessary in the mineral nutrition of tobacco. Since potassium, magnesium, and calcium are related in their biological and chemical effects, and because they are deficient in some soils, they have been selected for consideration. The malnutritional symptoms manifested by the tobacco plant when these elements singly and collectively are deficient in the media in which the plant is grown will be described and illustrated.

## POTASSIUM DEFICIENCY

The first of these to be considered is potassium. When the medium, whether it be water culture, soil pot culture, or soil in the field, is deficient in potassium, the growing tobacco plant exhibits characteristic abnormalities in leaf growth. (See Fig. 1.) The specific symptoms of potassium deficiency on this plant are in the early stages a yellowish mottling of the leaves with a bronze or copper overcast appearance. The centers of the mottled areas are usually dead or dying, and in the early stage these dead areas occur as numerous specks at the tip, around the margins, and between the veins of

[1]Paper read as part of the symposium on "Tobacco Research" at the meeting of the Society held in Washington, D. C., November 23, 1928.

[2]Associate Physiologist, Office of Tobacco and Plant Nutrition, Bureau of Plant Industry, U. S. Dept. of Agriculture, Washington, D. C.

the leaf. The tip of the leaf is usually the first part to show these symptoms. The growth of the leaf around the margins is checked, the result being a "rim-bound" condition or curling downward of the tip and margins. Leaves of plants suffering from potassium hunger are very rough. The small "specks" gradually enlarge and merge causing the margins and tip of the leaf to become ragged by forming dead areas. These dead areas under some conditions drop out, thus in extreme cases practically destroying the entire crop.

FIG. 1.—Tobacco plant in southern Maryland, showing effects of an insufficient supply of potassium in the soil. The tips and margins of the lower leaves are curved downward in a characteristic manner; the margins are more or less torn and ragged; the leaf surface is rough and puckered; the green color of the affected leaves has largely disappeared, especially at the tips and margins. (U. S. D. A. Yearbook 1927, Fig. 237.)

This may be due in a measure to parasitic leaf spot diseases, as the physiological breakdown resulting from potassium deficiency probably allows the organisms causing leaf spots to gain entrance into the leaf tissue and hasten its breakdown. (See Figs. 2 and 3.) In some cases the first stage, that of specking, is not found, the first symptoms following the mottling being a general dying of the tissue at the tip and margins of the leaf. The yield and quality of the cured product are materially lowered where potassium hunger is an important factor. The leaf is not only reduced in size, but it is thin and lifeless. The color is uneven and the numerous spots and specks described

previously on the growing leaf are present on the cured product. The burn of cured tobacco grown with an insufficient supply of potash is very poor.

FIG. 2.—Tobacco plants, flue-cured district, showing extreme damage sometimes caused by leaf spot when potassium is deficient. (U. S. D. A. Tech. Bul. 12, Fig. 4.)

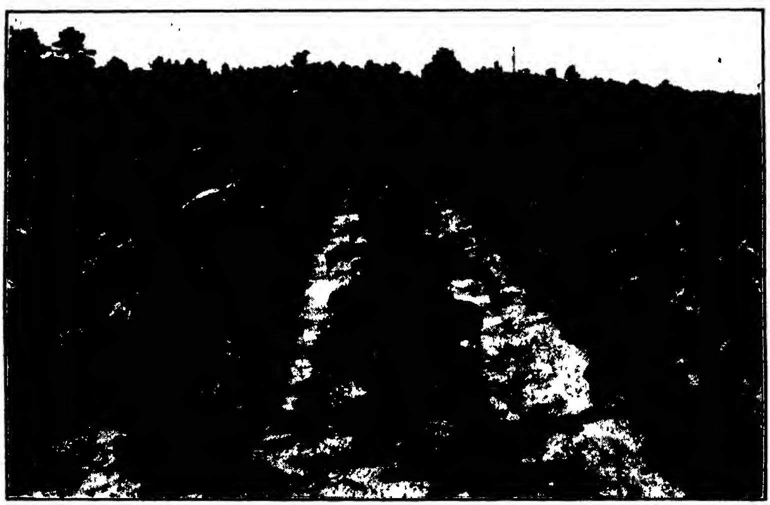


FIG. 3.—Tobacco plants, flue-cured district, showing comparative leaf smoothness when potassium is supplied under the same conditions as shown in Fig. 2. (U. S. D. A. Tech. Bul. 12, Fig. 5.)

## MAGNESIUM DEFICIENCY

When magnesium is deficient in the medium in which the plant is grown, the deficiency gives rise to definite symptoms in the leaf which are easily recognized. (See Fig. 4.) This deficiency usually occurs in severest form on sandy soils and sandy spots in the field during wet seasons, and hence is commonly known as "Sand Drown." When the growing crop exhibits these symptoms the yield is reduced and the quality of the product is lowered. The color of the cured leaf is irregular and the weight, body, and elasticity are affected unfavorably. Symptoms in the cured leaf are more readily recognized in bright flue-cured tobacco than in other types.

FIG. 4.—Tobacco plant, flue-cured type, showing characteristic symptoms of magnesium deficiency. Note that the plant as a whole and individual leaves have attained normal size and shape and the leaf surface is relatively smooth. The symptoms of this deficiency are more marked on the lower leaves. The veins retain their normal green color long after the leaf lamina become almost white. The leaf lamina usually does not die in local areas or spots as in potassium deficiency. (U. S. D. A. Year-book 1926, Fig. 145.)

As already stated, it is difficult in the field to determine the exact cause of a nutritional deficiency since there are so many factors involved which are not under control. However, by using pot cultures conditions can be more readily controlled, and it is possible to study and determine the cause of some of our tobacco problems. By growing a plant so that it gets little or no magnesium, that is watering the pot in which it is grown so as to leach the soil with a nutrient solution containing no magnesium, it is possible to produce the same characteristic blanching of the leaves as is seen in the field. When magnesium is supplied in parallel pot culture studies a marked increase in growth is noted and the healthy normal green color extends to the

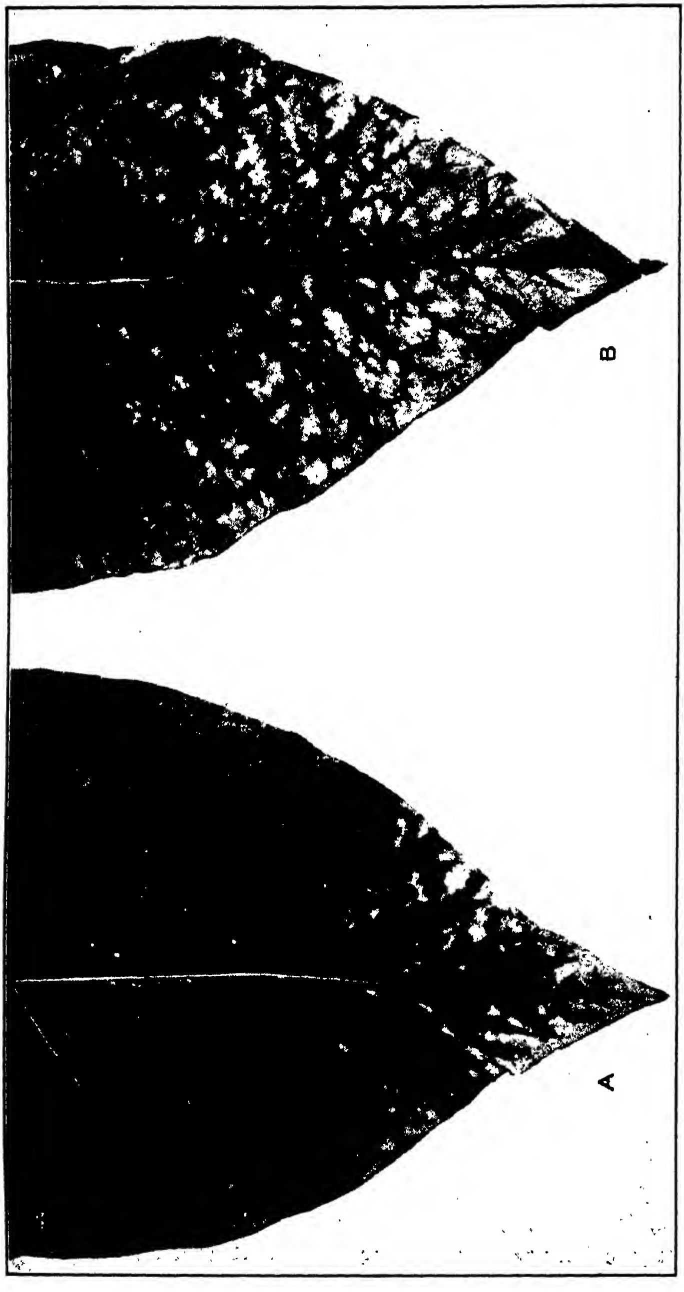



FIG. 5.—Tobacco leaves showing symptoms of potassium deficiency. The mottling begins at the leaf tip as shown in the initial stage (A) and progresses as shown in the later stage (B). Note the numerous small spots which represent dead tissue. This spotting or localized dying of the tissue distinguishes the symptoms of potassium deficiency from those of magnesium deficiency or sand drown. (U. S. D. A. Tech. Bul. 12, Pl. 2.)


FIG. 6.—Tobacco leaves, flue-cured type, typical of successive stages of magnesium deficiency or sand drown. Leaf A has lost practically all green color except at its base and along the large veins. These leaves represent very well the stages of loss of green color due to magnesium deficiency which may be observed on an individual plant from its base upward (A to D). Note that these leaves show no localized dying or spotting of the leaf tissue which is a major distinguishing char-

extreme bottom leaf of the plant, showing that the deficiency can be corrected by supplying magnesium.

The specific symptom of magnesium hunger is the loss of the green color at the tip and margins of the lower leaves of the plant. This loss of color seems to advance toward the base of the individual leaf and may extend to the upper leaves of the plant, depending upon the acuteness of the deficiency. In some instances the entire lower leaves may be almost white when the trouble is first recognized, although the veins and midrib tend to retain their normal green color. The symptoms in the field are identical with those produced under controlled conditions.

## DISTINCTION BETWEEN POTASSIUM DEFICIENCY AND MAGNESIUM DEFICIENCY

Potassium hunger and magnesium hunger as exhibited by the tobacco leaf resemble each other in that there is a loss of green color between the veins and at the leaf tip. (See Figs. 5 and 6.) The discolored portions, however, are of a different shade in the two cases, that of the leaf showing magnesium hunger being almost white, while that showing potassium hunger is usually yellow. The blanched tissue in the case of potassium hunger dies quicker than does that of the magnesium hunger leaf, causing characteristic "specking" and later falling out of the dead areas. The puckered or savoyed effect commonly seen in cases of pronounced potassium deficiency is absent in magnesium deficiency. In potassium hunger the leaf shows a curling downward of the tip and a curving under of the margins. These symptoms are not seen in magnesium hunger, the leaf surface usually remaining smooth because the translocation of this element from the lower leaves to the upper does not usually take place until the leaf has made its full growth. In the case of extreme magnesium hunger there may be a tendency for the edges of the leaf to turn upward. A plant showing magnesium hunger will show portions of the leaf retaining the normal green hue, while in the case of potassium hunger the green portions of the leaf show an abnormally dark green hue with a bluish cast. Potassium and magnesium hunger may occur on the same leaf, but the most pronounced symptom is that of potassium hunger. Potassium hunger is not so characteristically shown by the lower leaves of the plant first, as is magnesium hunger, and the symptoms may first appear on the tips of the leaves well up on the stalk. However, in potassium hunger, as in magnesium hunger, the tendency is for the lower leaves to show the greatest injury from the deficiency.

## CALCIUM DEFICIENCY

Calcium is another element lack of which produces characteristic symptoms on the tobacco plant. In potassium and magnesium deficiency the symptoms are more pronounced on the lower leaves of the plant, especially in the case of magnesium. In calcium deficiency the most pronounced symptoms are to be seen in the bud or top leaves of the plant. The leaves as they are unfolding from the bud become diseased and as they grow their tips and margins show abnormalities in shape. In extreme cases the death of the terminal bud or growing point is the result. Under field conditions when the element calcium is deficient growth is markedly reduced.

## EFFECTS PRODUCED WHEN MORE THAN ONE ELEMENT IS DEFICIENT

When all of these three bases are deficient in the medium in which the tobacco plant is growing the symptoms appear to be chiefly those of potassium deficiency, but the growth is greatly reduced, more so than if potassium alone is deficient. When only calcium and magnesium are deficient the growth is more reduced than if only one is deficient, but the most apparent symptoms on the plant are those of magnesium deficiency. Therefore, it would appear that one of these bases can function to a certain extent for another in certain growth processes and yet each has specific functions, so that characteristic deficiency symptoms result when the supply of any one of them is insufficient.

## 6. A WATER CULTURE TECHNIC FOR STUDIES IN TOBACCO NUTRITION[1]

A. B. BEAUMONT AND G. J. LARSINOS[2]

In studying problems of nutrition of the tobacco plant by means of water cultures at the Massachusetts Experiment Station, some methods and devices have been developed which may be helpful in similar studies with tobacco and other plants having some similar characters. Tobacco plants have been grown under conditions of partial and complete sterility. Four devices and methods of using them will be described.

In the study of the assimilation of different forms of nitrogen, it has been necessary to change the nutrient solution frequently, sometimes daily. It was soon discovered that the jar jacket suggested by Shive[3] and commonly used by plant physiologists for such work, was not suitable. This jacket, the purpose of which is to exclude light from the roots, is made of Bristol board cut at the top in such a way that it may be lap-folded to conform partially to the shoulder of the jar and is held in place by a string which, in studies with tobacco, must be untied and tied every time the solution is changed. With many cultures to change, this procedure was found to consume an undue amount of time. Further, it was found to be very difficult to avoid maltreatment of the lower leaves of the plant in the course of the operation. To obviate these objections, apparatus as shown in Fig. 1 was devised. This equipment has the following advantages over the common form, so far as tobacco is concerned: (a) Time required for changing solutions may be considerably reduced; (b) the jar cover may be readily removed, or the plant removed from the solution, for examination of the roots; and (c) maltreatment of the lower leaves of the plant may be reduced to a minimum.

The equipment just described has proved satisfactory with transplanted tobacco plants, but there is some objection to the use of transplants in nutrition studies. Previous growth in a nutrient solution affects the later behavior of a plant, and it appears that the larger a plant is at the time of transplanting, the more serious this factor becomes. In order to eliminate the effects of previous growth, the device shown in Fig. 2 was worked out. This is used with other

[1]Paper read as part of the symposium on "Tobacco Research" at the meeting of the Society held in Washington, D. C., November 23, 1928. Contribution No. 86, Massachusetts Agricultural Experiment Station, Amherst, Mass.

[2]Professor and Assistant, respectively.

[3]SHIVE, JOHN W. Physiological balance in nutrient media. Physiol. Res., 1:327-397. 1915.

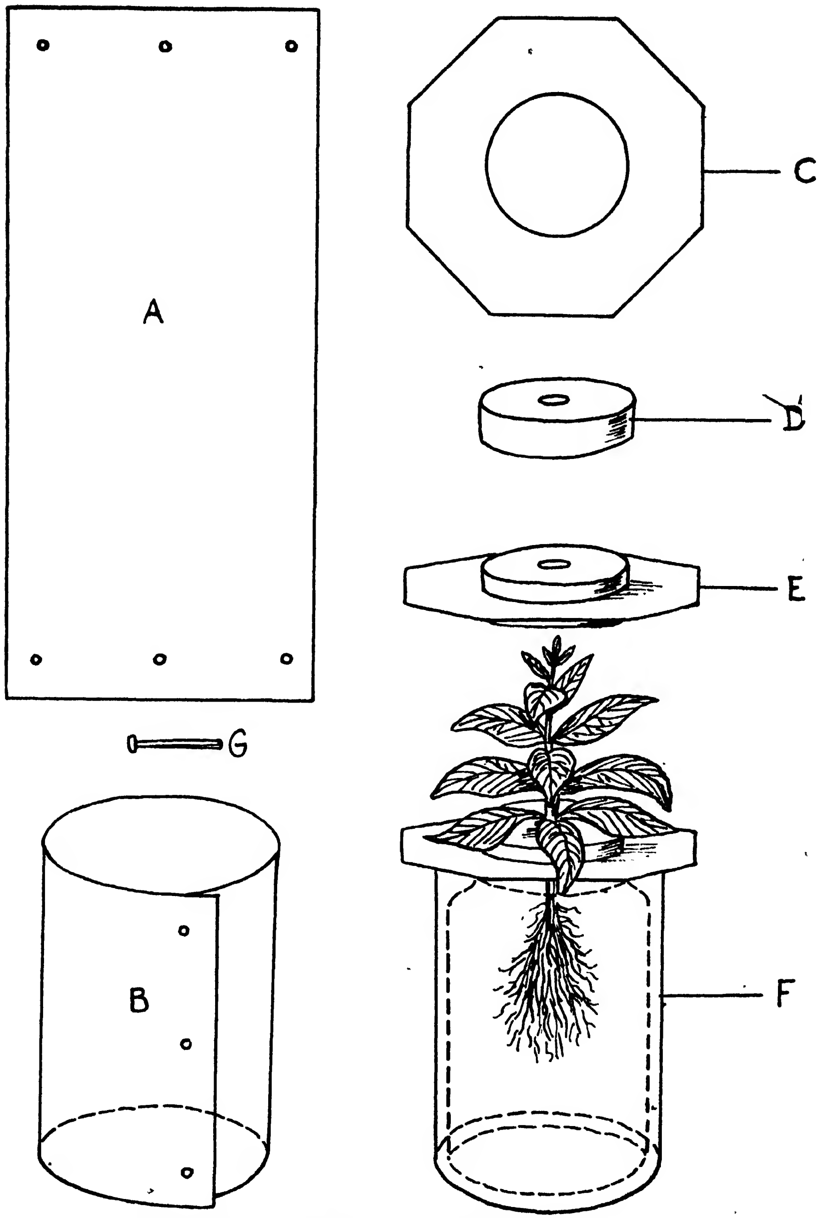



FIG. 1.—Apparatus for growing tobacco in water cultures. A, Bristol board unfolded; B, Bristol board folded and held together by brass fastener G; C, hexagonal cover of sheet metal, with hole for cork; D, flat cork with hole for plant; E, C and D assembled; F, entire apparatus assembled.

equipment as shown in Fig. 1. The device is very simple, consisting merely of a plug of absorbent cotton inserted in the hole of the cork in such a way that it serves both as a support for the seeds and as a wick for the nutrient solution. For seeds as small[4] as those of tobacco such a support is practically indispensable.

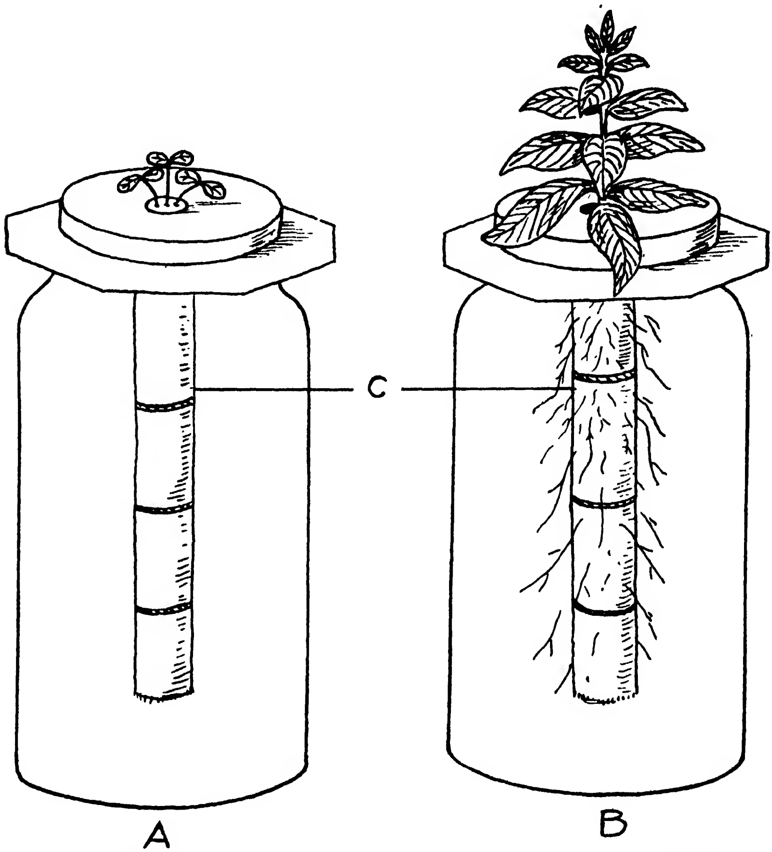



FIG. 2.—Showing use of wick C made of absorbent cotton; A, early growth stage; B, later growth.

More seeds should be planted on the cotton than are desired to develop into plants so that the plantlets may later be thinned to the required number. It has been found that tobacco and some grasses send their roots down thru the cotton wick as shown in Fig. 2. Owing

[4]Havana tobacco seeds have a long diameter of 500 to 600 microns and a short diameter of 300 to 400 microns. Approximately 10,000 seeds are required to make 1 gram.

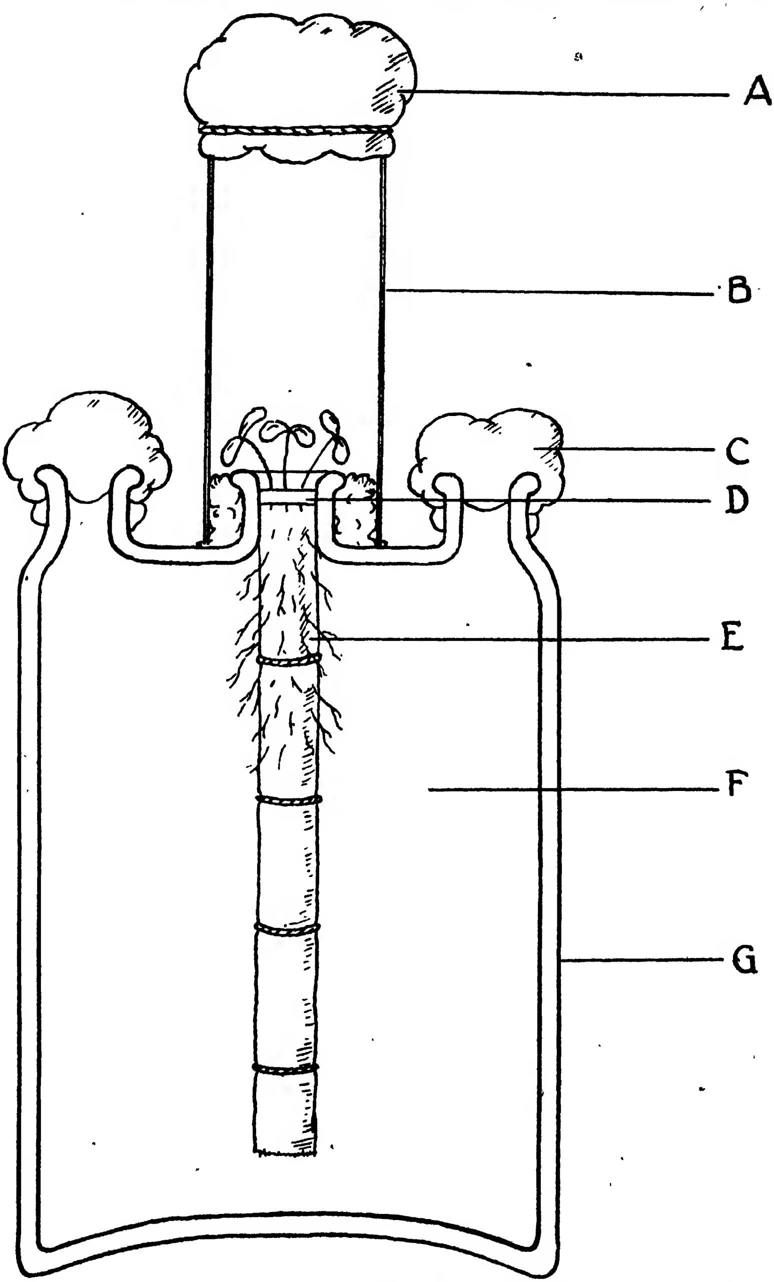



FIG. 3.—Equipment for growing small-seeded plants under sterile conditions. G, 3-neck Wolff bottle; E, plug and wick of absorbent cotton; D, nutrient agar; B, gas lamp chimney; openings covered with non-

to possible undue concentration of soluble salts on the exposed surface of the wick by evaporation, it is desirable either to cover the seeds with a lipless beaker or other transparent cover until the plants become large enough to reduce evaporation to a harmless point, or to

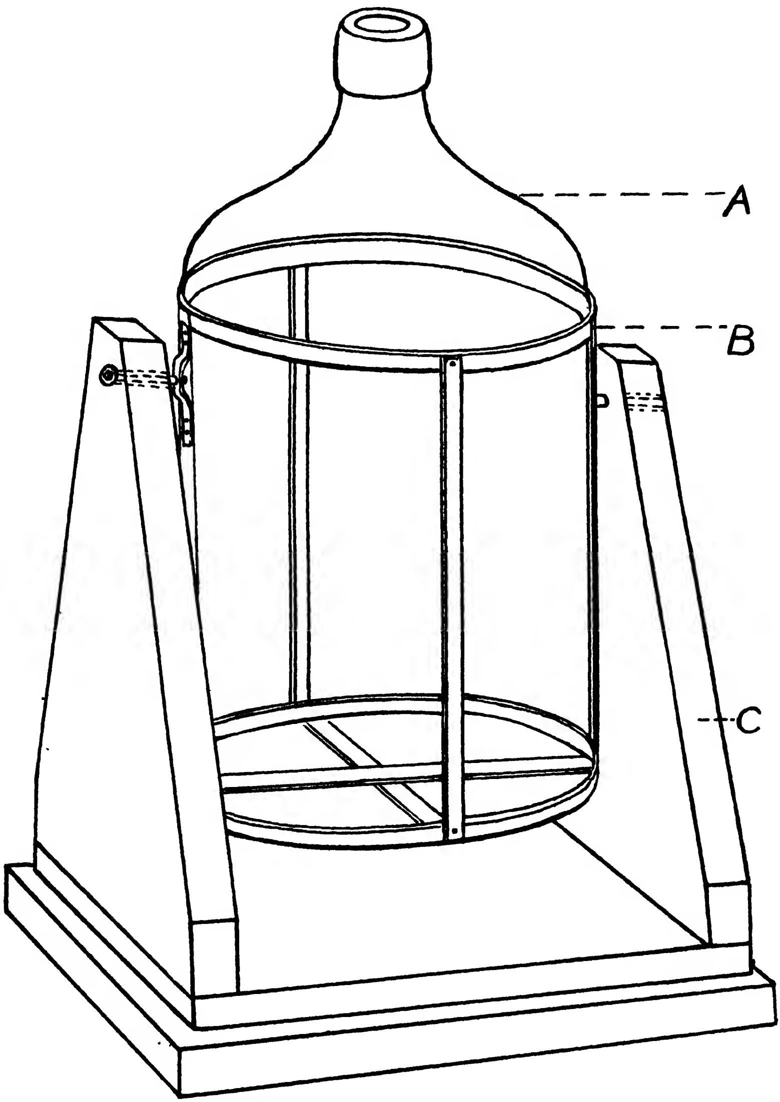



FIG. 4.—Shaking machine for agitating nutrient solutions containing slightly soluble salts. A, 5-gallon carboy; B, iron frame; C, heavy wooden support.

use distilled water instead of nutrient solution until the plantlets become established.

For the growing of plants under sterile conditions the apparatus shown in Fig. 3 is being used. This represents a slight modification and simplification of the form originally used and reported.[5] The principles involved are the same as those utilized with the apparatus of Fig. 2. The complete apparatus as shown, except for seeds, is sterilized with steam at 15 to 20 pounds pressure for 30 minutes. To reduce breakage of glassware, the sterilizer is heated very slowly, approximately one hour being allowed for raising the pressure to 15 pounds. The seeds are sterilized by means of a 1:1,000 solution of silver nitrate which was found to be especially effective for tobacco seed by Johnson and Murwin.[6] The seeds are placed in a small muslin bag and the bag of seeds, immersed in the silver nitrate solution, is thoroughly kneaded with a glass stirring rod to insure intimate contact between seeds and solution. The disinfected seeds are placed on the cotton plug after the apparatus has been steam sterilized. A layer of nutrient agar may be placed on the cotton plug before planting, to serve as an indicator of asepticism, if desired.

In some of our nutrition studies with tobacco a nutrient stock solution containing a high proportion of slightly soluble salts has been used. This condition has made it impossible to use a burette for measuring charges and very difficult to maintain the proper suspension of solids while preparing cultures. With a large number of cultures and frequent changes of solutions, large volumes of solution must be handled. A convenient shaker was made by mounting a 5-gallon carboy on an iron frame which was supported by a heavy wooden base in such a way that the stock solution could easily be agitated and charges drawn before settling occurred to any great extent (Fig. 4). This equipment has proved very helpful in facilitating the work with the type of nutrient solution used.

[5]Beaumont, A. B., and Larsinos, G. J. Method for growing small-seeded plants under sterile conditions. Science, 67:350–351. 1928.

[6]Johnson, James, and Murwin, H. F. Disinfection of tobacco seed against wildfire. Abs. in Phytopath., 14:28. 1924.

## 7. SOIL REACTION STUDIES ON THE CONNECTICUT TOBACCO CROP[1]

P. J. ANDERSON[2]

It has been known for the last 20 years that heavy liming of soils or heavy application of wood ashes or other alkaline materials brings on root-rot of tobacco. Such land runs out in a few years. Also, it is well known that in states where the soil is less acid, such as the limestone sections of Kentucky and Ohio, that tobacco cannot be grown continuously on the same land because this same root-rot becomes so prevalent and the crop so small that it is no longer profitable. Hence such sections must practice long rotations. On the other hand, the Yankee farmers of long ago also learned that a soil may be too acid for tobacco and long before we began to investigate it was a common practice to lime a soil which was just cleared from the brush where they wished to grow tobacco.

It is apparent then that a soil may be too acid or it may be too alkaline—or perhaps we should say it may be too nearly neutral for tobacco. This being admitted by all then it is obvious that somewhere between these two extremes there must be an optimum reaction where tobacco will grow at its best.

The object of our investigation then was to locate the optimum as nearly as we could, and the limits of good growth on either side, and to work out a rapid technic by which we could test the farmer's soil and tell him whether it was too acid or alkaline or optimum and to advise him, if possible, as to methods of correcting it.

Without going into detail concerning the early investigations, it will suffice to say that we finally decided that a determination of the hydrogen-ion concentration was the most satisfactory. At first we used the colorimetric method by means of the Morgan LaMotte apparatus. Later we substituted a Youden's potentiometer. Either of these methods is satisfactory and sufficiently accurate for the work. We chose the potentiometer principally because of its speedier operation.

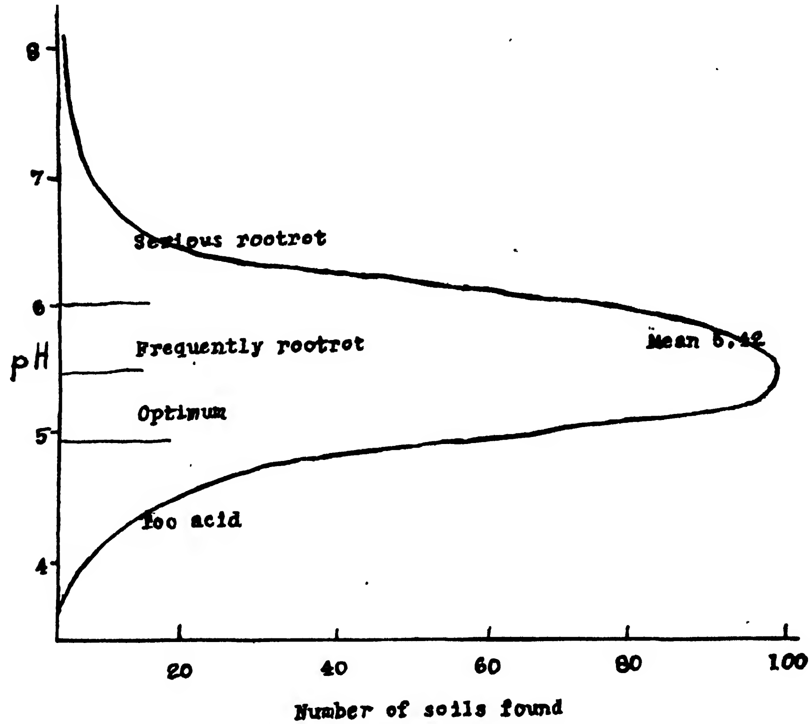
The major part of the work on this project has been an extensive and intensive field survey. We have tested soil samples from over 2,000 fields throughout the entire tobacco-growing region of New England. We have taken notes on the condition of the tobacco on these fields and correlated them with the soil reaction. This has been

[1]Paper read as part of the symposium on "Tobacco Research" at the meeting of the Society held at Washington, D. C., November 23, 1928.

[2]Pathologist in Charge, Connecticut Tobacco Substation, Windsor, Conn.

supplemented wherever desirable by greenhouse and laboratory work.

A frequency distribution curve of the reaction of these soils runs about thus:




The maximum number are in the range from 5 to 5.6, the mean being at 5.42. Soils as acid as 4.2 are very rare. Also tobacco soils above 7 are rarely found.

We have never found good tobacco growing on land which tested as low as 4.2 and frequently it is poor up to 4.5. We have come to the conclusion, therefore, that all tobacco soils should test at least above 4.5 to get good growth. Although there are many between 4.5 and 5.0 which are growing good tobacco, there are others which are not. Even rank-growing fields do not produce the best quality tobacco. Taking into consideration both yield and quality, the optimum reaction for tobacco soils is between 5.0 and 5.6.

In the range above 5.6 we begin to be troubled with root-rot. There is a doubtful zone between 5.6 and 6.0 where many fields are satisfactory while others are falling off in growth. Above 6.0, however, we have only very rarely found a field which had grown tobacco

for many years without bad results. From 6.0 pH up it is a rule that the higher the reaction, the worse the root-rot and the poorer the growth.

## EXPLANATION OF INJURIOUS EFFECT OF EXTREME ACIDITY

Seeking an explanation of the injury caused to tobacco by extreme acidity we naturally think first that it may be due to the arresting of nitrification. This might be a partial explanation but in the average tobacco mixture there is usually considerable nitrate which needs no nitrification to make it soluble. Also, it has been shown that there is considerable nitrification in acid soils not traceable to Azotobacter. The symptoms are not those of nitrogen starvation. The soil acid is certainly not concentrated enough actually to poison the roots because the roots are usually white and sound. We are inclined to believe that the injury is due to soluble manganese or aluminum salts which are liberated at this reaction. In the field we get the same leaf symptoms as we get when we treat potted plants with manganese sulfate. We are not so certain of aluminum. These symptoms can be made to disappear when either lime or superphosphate is applied to the field.

The explanation of the poor growth on soils which are too nearly neutral is the presence of root-rot as previously mentioned. However, it has been found at the Massachusetts Station and in Canada that a heavy application of lime may be detrimental to the growth of tobacco even in the absence of root-rot.

## HOW THE FARMER MAY KEEP HIS SOIL AT OPTIMUM REACTION

First of all the farmer must have his soil tested periodically. He cannot intelligently start to correct until he knows which way to go. If his soils are too acid, the answer is simple. He need only supply enough lime or woodashes to bring it up to around 5.0 pH. We have recommended that he use rather small doses and repeat them rather than to try to bring his soil up all at once. Below 4.5 he may use 1,000 pounds of burnt lime per acre. Between 4.5 and 5.0 he should not use more than 500 pounds.

If his soil is optimum or too high he should avoid lime and also any fertilizer which would have an alkaline tendency. If his soil is too high and the crop is suffering from root-rot it is not so simple. We have used sulfur, sulfate of ammonia, and aluminum sulfate, but their use is not very practicable. There is an injurious effect from the use of too much sulfur in any form.

Perhaps the most practical thing is to abandon for a time the use of this field or to plant root-rot resistant strains of tobacco.

# 8. SOME FACTORS AFFECTING THE NICOTINE CONTENT OF TOBACCO[1]

CHARLES W. BACON[2]

## TOBACCO TYPES

Nicotine is the characteristic constituent of all tobacco and tobacco products. It is undoubtedly the most interesting and at the same time the one upon which the popularity of the "weed" depends. Although only one of a large group of vegetable alkaloids, it has made a name for itself in history, literature, romance, and more recently in the realm of advertising.

Tobacco is grown the world over and consequently a very large number of types and varieties has been developed; many of them grown only in a particular locality. In this country a considerable number is grown and, together with others imported, used in the large variety of tobacco products that is manufactured here.

To call attention to some of the types in particular Table 1 has been made listing some of the more important ones and at the same time, in a general way, indicating their relative nicotine content. That the percentage of nicotine in them can not be given with any degree of accuracy is due to the fact that it is affected by so many different factors; a few of the more important of which it is the object of this paper to point out.

TABLE 1.—*Relative nicotine content of important tobacco types.*

| Tobacco types | Nicotine content |
|---|---|
| *Nicotiana rustica* | High |
| Dark fire-cured | High |
| Pennsylvania cigar filler | High |
| Connecticut cigar wrapper | Medium |
| Imported Cuban | Medium |
| Burley | Medium |
| Flue-cured | Medium |
| Turkish | Low |
| Maryland | Low |

The Maryland and Turkish are low in nicotine; the flue-cured, Burley, Cuban and Connecticut are medium; and the Pennsylvania, dark fire-cured, and especially *Nicotiana rustica* are high in nicotine content. *Nicotiana rustica* (Fig. 1), while one of the old native

[1]Paper read as part of the symposium on "Tobacco Research" at the meeting of the Society held in Washington, D. C., November 23, 1928.

[2]Associate Physiologist, Office of Tobacco and Plant Nutrition, Bureau of Plant Industry, U. S. Dept. of Agriculture, Washington, D. C.

American species, is not generally known nor used as tobacco in this country, but owing to its unusually high nicotine content offers possibilities for being grown solely for the nicotine it contains, which of course has a very wide use as an insecticide. The amount of nicotine in *rustica* varies but sometimes reaches 10 to 12%, and attempts are now under way to grow it commercially as a source of that alkaloid.

FIG. 1.—Mature plant of *Nicotiana rustica.*

## DISTRIBUTION IN THE PLANT

With the exception of the seed, all parts of the tobacco plant at all stages of growth contain nicotine, the amount present varying from a trace in the seedlings to very large quantities in the mature leaves. An interesting study of the distribution in the plant and also at different stages of growth has been made by two French investigators, Chuard and Mellet (1)[3] and their results are given in Table 2. The amount present in the seedlings is only a trace and remains at a low figure until after the plants have been topped, but thereafter increases rapidly in the leaves. The quantities in the stalks and roots are very much lower and do not increase with the age of the plant.

TABLE 2.—*Distribution of nicotine in the different parts of the tobacco plant and change in content with the age of the plant.**

| Date of sample | Content of nicotine | | | |
|---|---|---|---|---|
| | Leaves | Stalks | Roots | Suckers |
| | % | % | % | % |
| June 16 (transplanted) | 0.35 | — | 0.15 | — |
| July 14 (just before topping) | 0.34 | 0.08 | 0.45 | — |
| August 9 | 3.12 | 0.61 | 0.69 | 1.04 |
| September 18 | 4.79 | 0.52 | 0.64 | 1.27 |
| November 4 | — | 0.47 | 0.53 | 1.04 |

*The seed was sowed on April 25 and on May 15 analysis of entire small plants showed only a trace of nicotine. Data of Chuard and Mellet (1).

Table 3 has been made from some of our own results showing the quantities ordinarily present in the leaves, stalks, and leaf-stems of a number of the more common types. It will be seen that while the values for the leaf may be quite high those for the stalks and leaf-

TABLE 3.—*Nicotine content of several tobacco types and varieties and the distribution in the different parts of the plant.*

| Type of tobacco | Content of nicotine | |
|---|---|---|
| | Stalk | Whole leaf |
| | % | % |
| *Rustica* | 2.28 | 8.19 |
| Connecticut | 0.32 | 3.15 |
| Flue-cured | 0.30 | 2.26 |
| Maryland | 0.19 | 0.79 |
| Connecticut varieties (2) | Leaf stem | Leaf web |
| | % | % |
| Havana Seed, primed; cured | 0.50 | 4.74 |
| Havana Seed, stalk-cured | 0.55 | 5.21 |
| John Williams Broadleaf, primed; cured | 0.78 | 3.43 |
| Halladay Havana Seed, primed; cured | 0.42 | 2.53 |
| Halladay Havana Seed, stalk-cured | 0.17 | 1.89 |

[3]Reference by number is to "Literature Cited," p. 167.

stems are low, except in the case of the *rustica*. While the values for the by-products are low, nevertheless it is from this material that most of the nicotine used as an insecticide is obtained.

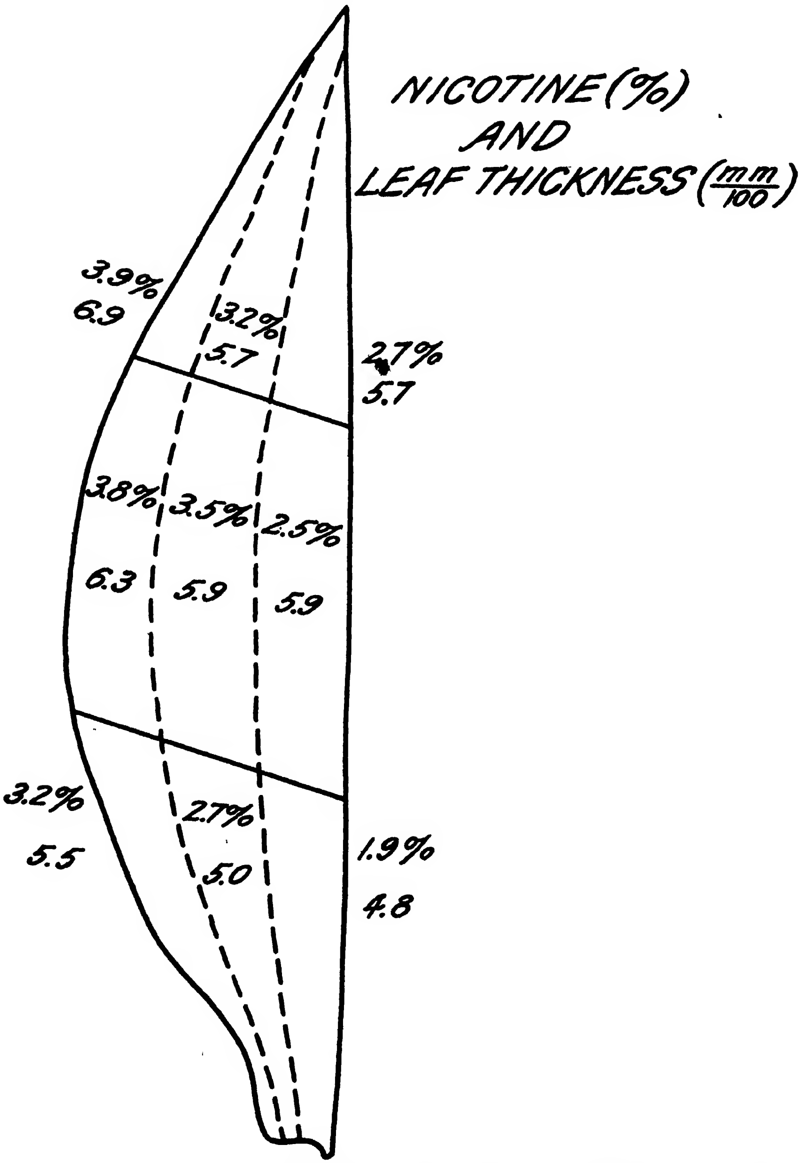



FIG. 2.—Relation of nicotine content to leaf thickness in different parts of the tobacco leaf. (Data of J. B. Jehan (4) on Kentucky Burley tobacco.)

A more specialized study of distribution has been made by Jehan (4), who studied the nicotine content of various parts of the leaf itself and at the same time the thickness of the several parts (using of course corresponding parts of a number of leaves). His work on one type of tobacco (Kentucky Burley) is graphically presented in Fig. 2 where the leaf is divided into three zones, exterior, median, and interior; each zone divided into three sections, top, middle, and lower; and the nicotine percentage and leaf thickness shown on the nine areas. The thickness as a rule was found to increase from the petiole to the tip and from the midrib to the margin; the nicotine values showing a similar variation. Also, from a similar study of various types he found that there was a close agreement between the average nicotine content and the average thickness of the leaf.

## CULTURAL PRACTICE

Tobacco culture in any particular locality has become highly specialized over a long period of years, but there is one practice, that of topping, that is almost universally used, although with considerable modification. It not only has a profound effect on the nicotine content, but also determines in no small degree the characteristics and properties of the tobacco type itself. Some of our results, as well as those of the Pennsylvania State College (3) on the effect of topping on the nicotine produced in the plant, are shown in Table 4.

The advantage gained by this practice is very clearly indicated not alone in the percentage of the alkaloid on the basis of the whole plant

TABLE 4.—*Effect of topping on the nicotine content of Nicotiana rustica.*

| Part of plant | Nicotine content: Untreated | Topped* | Topped and suckered | Suckered |
|---|---|---|---|---|
| | % | % | % | % |
| Leaves | 2.50 | 4.51 | 7.46 | — |
| Stalks | 0.66 | 1.06 | 1.94 | — |
| Whole plant | 1.86 | 3.31 | 5.88 | — |
| | Grams per plant | Grams per plant | Grams per plant | |
| | 2.66 | 5.64 | 9.74 | — |
| | % | % | % | % |
| Whole plant† | 1.61 | 2.75 | 4.40 | 3.79 |
| | Grams per plant | Grams per plant | Grams per plant | Grams per plant |
| | 2.32 | 4.68 | 5.46 | 5.46 |

*Suckers also topped in first series.

†Data of Haley, Gardner, and Whitney (3).

but also in the amount produced per plant. The percentage was increased in one case from 1.86 in the untreated to 5.88 in the plants that were topped and suckered. The number of grams actually formed per plant was only 2.66 in the first case and 9.74 in the second. The confining of all growth to that of the leaves alone, although involving considerable labor with this particular type, very greatly increases the yield of nicotine.

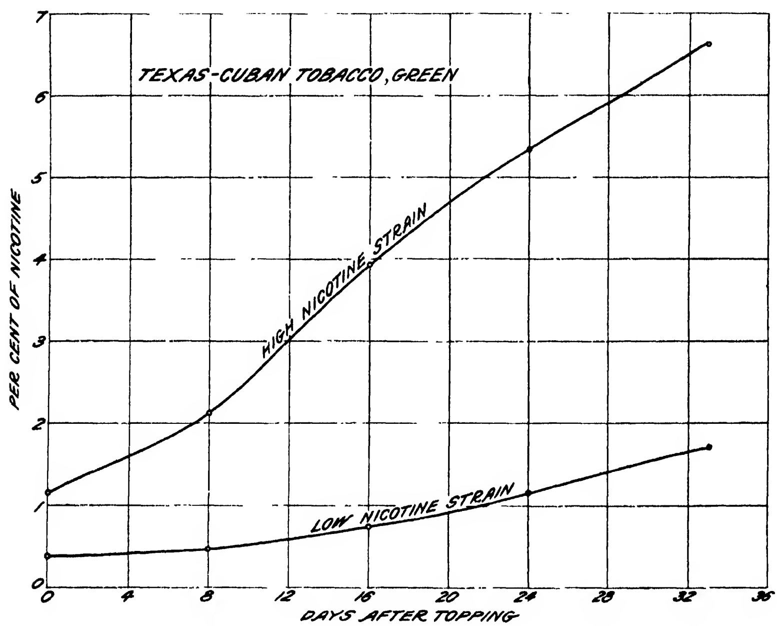



FIG. 3.—Progressive change of nicotine content with maturing or ripening of two strains of tobacco.

## RIPENING

Attention was called in connection with the discussion of distribution (Table 2) to the fact that the amount of nicotine present in tobacco is small until after topping has taken place and it should be emphasized that the topping (breaking off the bud or flower head) certainly marks the beginning of rapid accumulation of nicotine in the plant. As soon as this occurs the growth of the plant becomes restricted to a certain number of leaves that rapidly increase in size and thickness; that is, the leaves soon take on the characteristics ordinarily associated with maturing and ripening.

In order to follow the changes in the nicotine content during this period a series of five samples was gathered from selected plants at

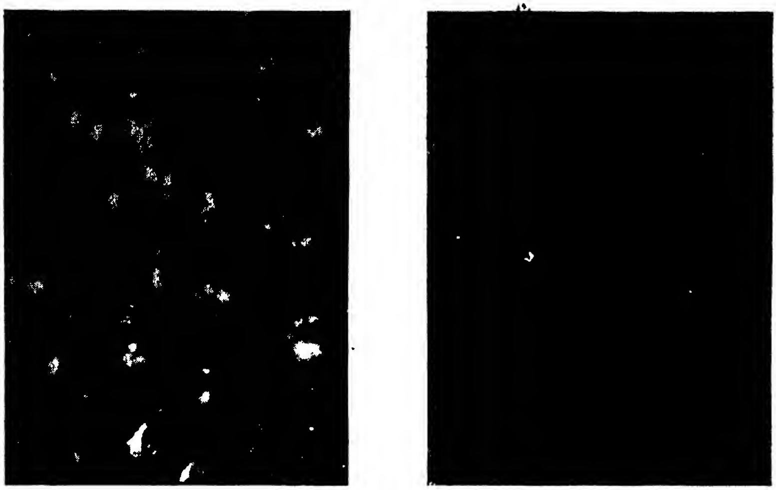


FIG. 4.—Difference in appearance of mature (at left) and green tobacco leaves (at right).

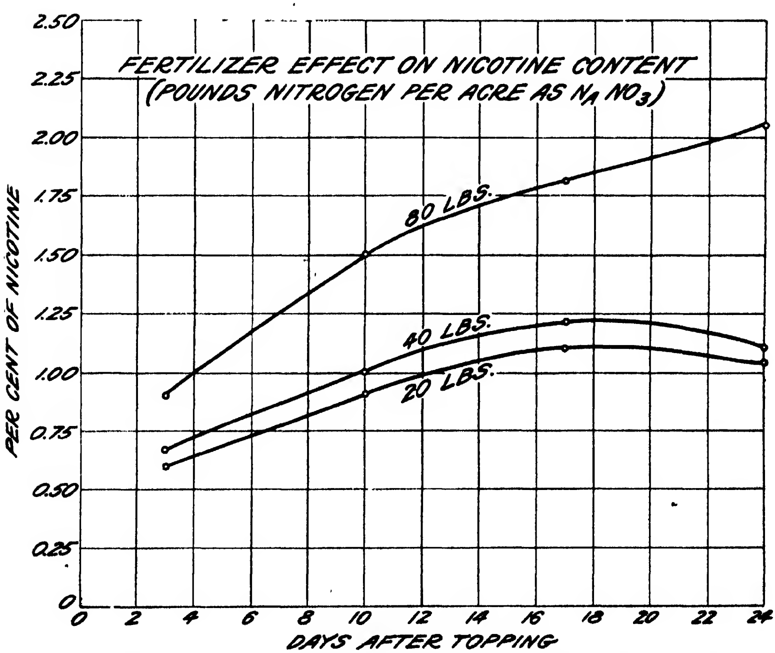



FIG. 5.—Effect of sodium nitrate as a fertilizer on nicotine content of Maryland tobacco.

intervals of about a week, beginning at the time of topping, and their nicotine content determined. The results of two such series of pickings from a low- and a high-nicotine strain of Texas-Cuban tobacco are shown in Fig. 3. The leaves were not allowed to cure, but were first killed by the use of chloroform and then allowed to dry out in the green state. Both curves show the increase of nicotine during the

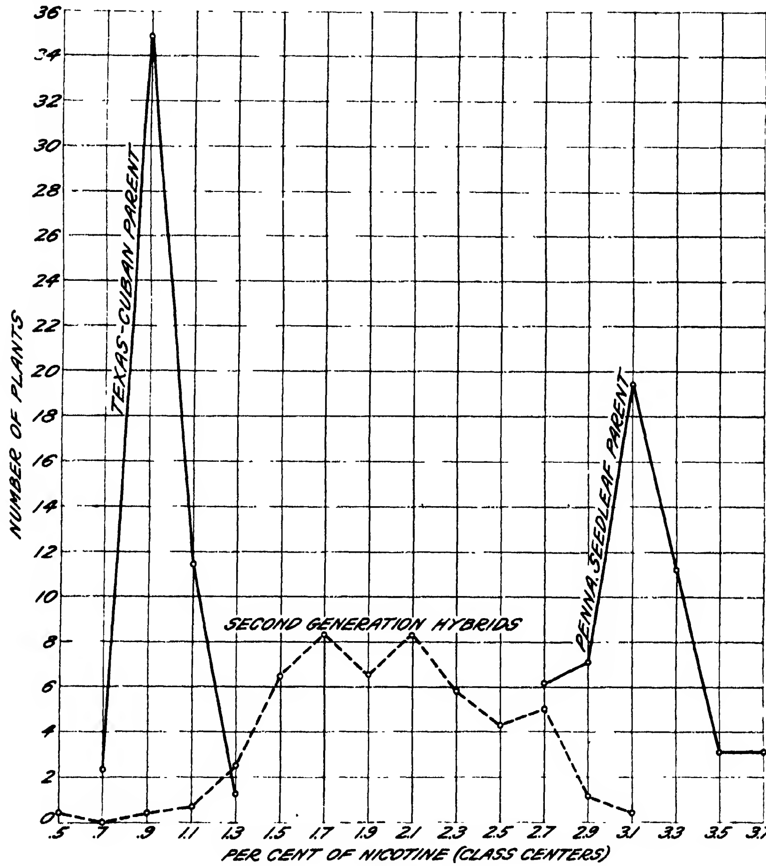



FIG. 6.—Frequency distribution of nicotine content of second generation hybrids and the parents, all grown under the same conditions. Data calculated on a basis of 50 plants of each lot.

maturing or ripening of the leaves (from about 1 to 7% in the high strain), although of course the change in the low-nicotine strain is much less.

One field characteristic associated with the ripening of the leaf and its increased nicotine content is the formation of yellow-colored

areas or the general yellowing out of the whole leaf. This appearance as contrasted with that of the green immature leaf is shown in Fig. 4 illustrating sections of two such leaves.

## FERTILIZER TREATMENT

Since fertilizers have such a marked effect it would be expected that they would also influence the nicotine content and the result of a study of the application of nitrate of soda in three different rates is shown in Fig. 5. Samples from the three plats were taken at intervals as in the previous study and the leaves were cured before being analyzed. The curves show the marked raising of the nicotine content by the high nitrogen application and also the usual increase with the maturity of the leaves.

## HYBRIDIZATION

The marked difference in nicotine content of varieties mentioned in the first section of this paper suggests at once the effect of hybridizing the high- and low-nicotine types. A number of such studies have been made and the results obtained from one such hybrid are shown in Fig. 6. Texas-Cuban was crossed with a Pennsylvania Seedleaf type and the results of the analyses of 139 of the second generation hybrids, 43 of one parent, and 49 of the other, all grown the same year and all calculated to a uniform basis of 50, are shown in the curves. In making the curves the data were first arranged into classes with a range of 0.2% of nicotine and then the number of individuals found in them was plotted against the class centers. The data are given simply to show the trend of results to be expected from hybridizing rather than to discuss the genetic considerations involved.

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# EFFECT OF DATE OF SEEDING OF WINTER WHEAT UPON SOME PHYSIOLOGICAL CHANGES OF THE PLANT DURING THE WINTER SEASON[1]

GEORGE JANSSEN[2]

In a subsequent paper (9)[3] on the development of the winter wheat plant it will be shown that a certain amount of crown development of the plant in the fall is essential for the greatest winter survival and for normal resumption of plant growth the following spring. The various stages of development obtained by the winter wheat plant, as a result of periodic seedings, is shown in this investigation. It was concluded, however, that the stage of morphological development could not be absolutely correlated with the winter-hardiness of the plant protoplasm. This and other studies suggested differences in the chemical composition of the plant crowns, and that this might in a large measure be responsible for the varying degrees of hardiness in the plant. The universal concept that a well-developed crown system acts only as a physical protection to the plant was unsubstantiated. It is just as logical to assume that the kind and amount of reserves stored in the crowns and the rate at which they are subsequently respired in the dormant season would bear an important relation to the manner in which the plant will survive the winter and also determine the vigor with which the plant will begin new growth the following spring.

## OBJECT OF EXPERIMENT

It is shown in the second paper (9) that differences in degree of hardiness of the winter wheat plant, at different stages of development, resulting from successive seedings made in the fall, could not in all instances be attributed to the degree of root and top development. It was the purpose of the present experiment, therefore, to study the

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The author wishes to acknowledge his indebtedness especially to Dr. James G. Dickson of the Plant Pathology Department and Dr. E. J. Kraus of the Botany Department for their helpful suggestions and encouragement during the entire work; to Professor B. D. Leith of the Agronomy Department for his kindness in furnishing assistance and directions in carrying out the work from an agronomic phase; and to Professor W. E. Tottingham of the Plant Chemistry Department for his hearty cooperation in giving directions on the chemical phases and permitting portions of the work to be carried on in his laboratories.

[3]Reference by number is to "Literature Cited," p. 198.

composition of the plant crowns and the general physiological processes which took place in them at various stages of growth during the fall and winter dormant season.

## METHODS

The plants for analysis were collected uniformly at the same time of the day, taken immediately to the laboratory, roots and leaves (area) cut away from the crowns, and the latter dried in the oven in the regular manner as described below. A record was made in each instance of the number of plants taken from each date of seeding so as to make possible a determination of increase and decrease in the weight of individual plants and various compounds present in the plant.

Chemical analyses were made on dried plant tissue. The method of drying the plant tissue was the same as that reported by McGillivray (13). This method, according to Link and Tottingham (12), offered the least alteration in the carbohydrate content due to enzymatic and respiratory activity. The dry plant tissue was then ground sufficiently fine to pass through an 80-mesh sieve and was stored in tightly stoppered bottles for analytical purposes.

Chemical analyses were made for reducing sugars, sucrose, total sugars, dextrins, starches, hemicellulose, soluble pentosan, insoluble pentosan, and total pentosan. Total nitrogen was determined in all instances, but the nitrogen distribution in the green material was made only on samples collected in the fall of 1924.

Material was usually collected for carbohydrate and total nitrogen analysis the same hour of the day. In all instances dried materials were used. In all the chemical analytical work only the crown of the plant was used after the leaves and roots were cut away. In all instances at least 1,800 to 2,000 plants were used. Reducing sugars, total sugars, and hemicellulose were determined on 2-gram samples after methods described by Leukel (10). Sucrose and dextrins were analyzed in the same manner as that given by Murneek (16). The reducing power of the carbohydrates was determined under the Munson and Walker conditions. The amount of copper reduced was then titrated by the Shaffer and Hartman (26) titration method. The sugar equivalents in terms of dextrose were obtained from Munson and Walker (17) tables.

### PENTOSANS

The pentosans were determined by the method given in the Official Methods of the A. O. A. C. Two-gram samples were used in every case. Lipoids were first extracted from the sample with anhydrous and alcohol-free ether.

### SOLUBLE PENTOSANS

The lipoid-free residue was treated with 300 cc of hot water for 24 hours under a reflux condenser in order to extract the soluble pentose sugars. The mixture was then filtered, washed with hot water, and the filtrate evaporated to 50 cc. Sufficient HCl was added to bring the solution to 12% concentration of HCl. The pentosan was then determined in the regular manner as described in the Official Methods of the A. O. A. C.

### INSOLUBLE PENTOSANS

The residue from the soluble pentosan extraction was taken up with 100 cc of HCl (Sp. Gr. 1.06) and the pentosan determination made according to the regular method given in the Official Methods. The percentages of pentosan were figured from Krober's tables given in the Official Methods of the A. O. A. C. It should be noted that no attempt was made to remove the hexose sugars previous to the pentosan determinations as it is assumed that these did not interfere with the furfural yield.

### NITROGEN

Total nitrogen was determined according to the Gunning method modified to include the nitrogen of nitrates as given in the Official Methods of the A. O. A. C.

### NITROGEN DISTRIBUTION

The plant material used for the study of the distribution of total nitrogen was collected in the morning, and extractions were made immediately. Thus in a few hours the work was carried to the point where there was little danger from further enzymatic change. This procedure was followed uniformly throughout all the determinations. The nitrogen distribution was determined according to the procedure given by Osborn (20, 21) and Chibnall (3, 4) and modified by Tottingham (27). The detail of extraction is given by McGillivray (13), but in these analyses 50-gram samples were used for water extraction and two 20-gram samples for moisture determination. The ground samples were washed with about 1,500 cc of water. Total nitrogen was determined on the total soluble filtrate and protein nitrogen in the same manner as described by McGillivray (13).

## EXPERIMENTAL RESULTS

### PERCENTAGE WINTERKILLING

In order that a correlation could be made between the winterhardiness of the plants with the chemical changes which might occur in the plant, the percentage of winterkilling was determined on the

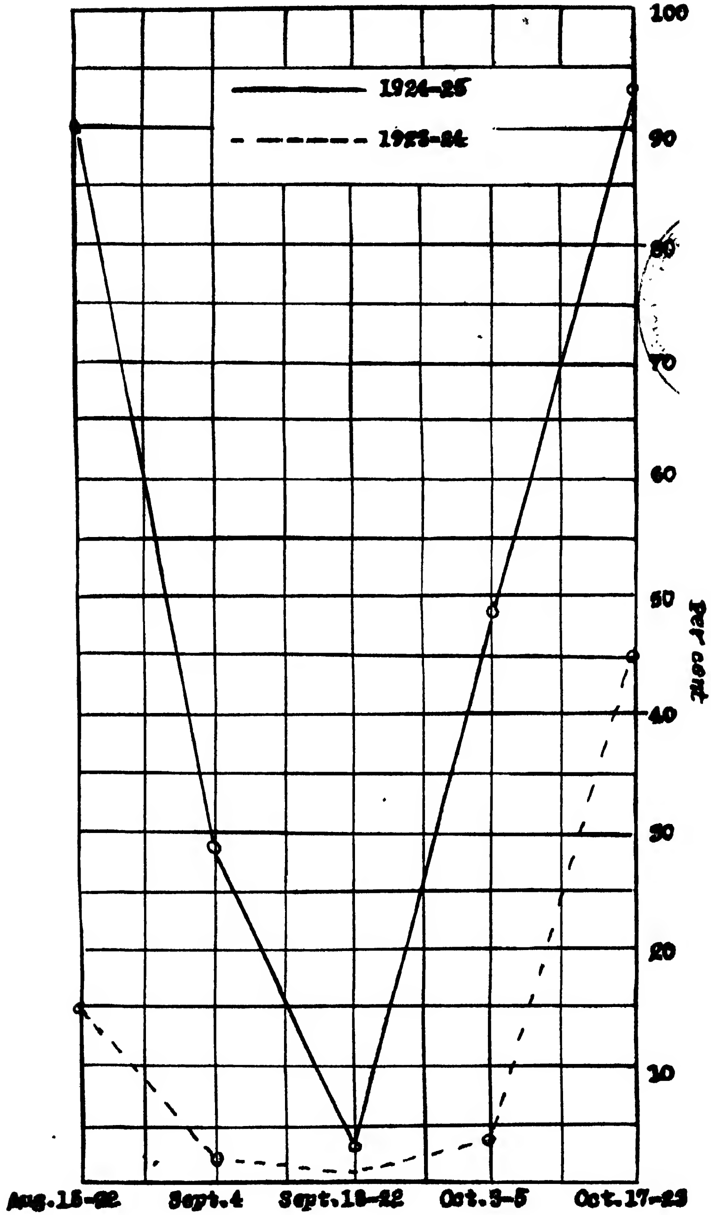


FIG. 1.—Showing the percentages of winterkilling of winter wheat plants which occurred during the winters of 1923 to 1925, inclusive, on five periodic plantings made during the fall season.

various dates of seeding test plats. These percentages are given in Fig. 1. These percentages were obtained by actual plant counts made in the fall and spring of the year. This figure is self explanatory, however, it should be stated that the high plant mortality in the late dates of seeding, October 5 and especially October 23, in a large measure was not due to an actual killing of the cell protoplasm during the winter, but to a killing of the plant recognized as "heaving" or the raising of the plant from the soil in the spring due to alternate freezing and thawing. This type of injury is discussed more fully in the later paper (9). From a winterhardiness standpoint the best dates

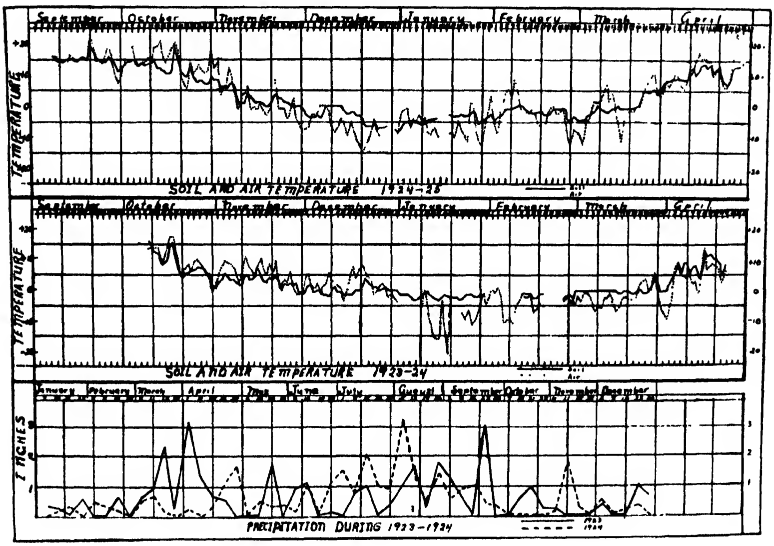


FIG. 2.—Graphs showing average daily soil and air temperature for the seasons 1923 to 1925, and precipitation for the years 1923 to 1924.

of seeding for the years 1923 to 1925 are found to be in the following order, from the best to the poorest, September 18 to 22, September 4, October 3 to 5, August 15 to 22, and October 17 to 23. These results compare favorably with yields obtained from these test plats over a period of seven years (9).

## TEMPERATURE AND MOISTURE

The temperature and moisture variations for the years 1923 to 1925 are given in Fig. 2. Considerable difference will be noted in the distribution of the moisture for the two years. How the moisture relation bears on the fall development of the plant as well as on its

winterhardiness is discussed in a subsequent paper (9). It should be noted here that the soil temperature (2 inches below the surface) fluctuated very much less than air temperature, also that even though the soil froze to a depth of several feet, the temperature 2 inches below the surface as an average seldom went below —5° C, whereas the air temperature was very erratic.

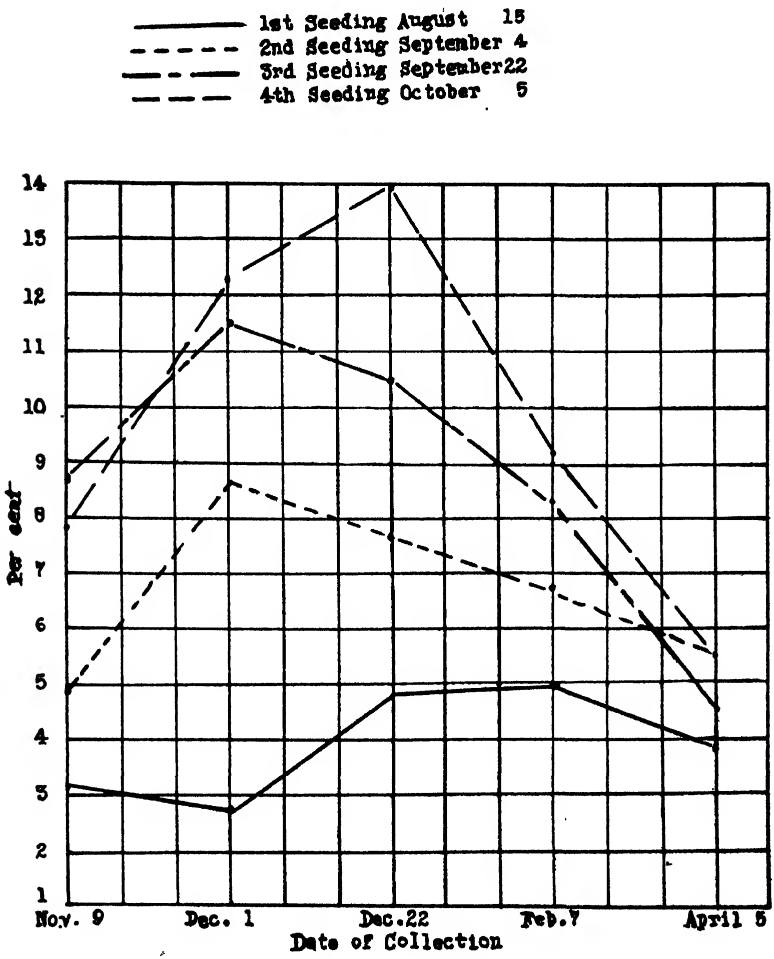


FIG. 3.—Showing percentage of sucrose in winter wheat plant (crowns) at various dates of collection made during the fall and winter months of 1923 and 1924. Plant collections were made from four dates of seeding.

SUGARS, DEXTRIN, STARCH, AND HEMICELLULOSES

Data of all chemical analyses, except in nitrogen distribution, made on plants collected in 1923 are presented in Table 1 and for 1924 in Table 2.

The reducing sugars in the plant tissue fluctuate from one date of sampling to another. These fluctuations cannot be accounted for, but may possibly be due to the relative variable carbon assimilation capacity of the plants from the different dates of seeding.

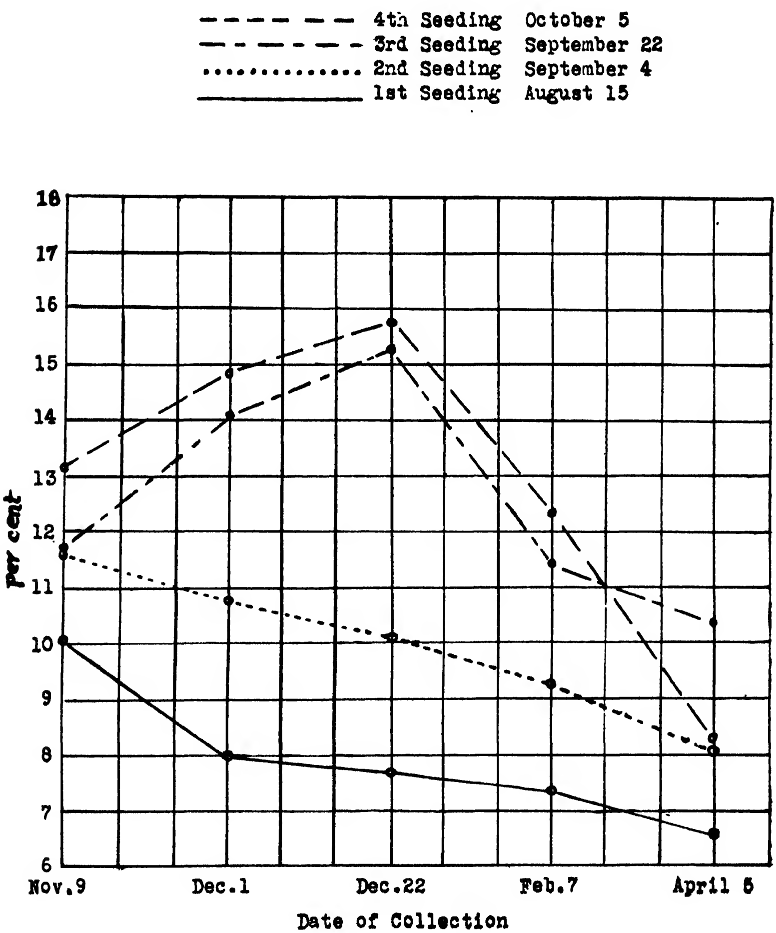


FIG. 4.—Showing percentage of total sugars in winter wheat plant (crowns) at various dates of collection made during the fall and winter months of 1923 and 1924. Plant collections were made from four dates of seeding.

TABLE 1.—*Showing the relative change of carbohydrate and nitrogneous compounds in winter wheat plant crowns at various stages of development during the fall growing and winter dormant seasons of 1923–24.*

| Date planted | Date collected | Reducing sugars | Sucrose | Total sugar | Dextrins | Soluble starch | Starch | Hemi-cellulose | Fats | Total nitrogen | Pentosans Soluble | Pentosans Insoluble | Pentosans Total | Carbohydrates Water-soluble | Carbohydrates Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | % | % | % | % | % | % | % | % | % | % | % | % | % | % |
| Aug. 15 | 11-9-23 | 2.97 | 3.13 | 10.02 | 7.37 | 0.0 | 0.79 | 15.3 | 1.55 | 2.82 | 3.04 | 15.30 | 18.41 | 17.57 | 33.66 |
| | 12-1-23 | 1.65 | 2.74 | 8.00 | 6.90 | 0.0 | 0.508 | 19.75 | 1.55 | 2.54 | 1.70 | 15.01 | 16.71 | 14.90 | 35.15 |
| | 12-22-23 | 2.30 | 4.84 | 7.70 | 6.32 | 0.21 | 0.507 | 18.40 | 1.87 | 2.83 | 2.06 | 8.21 | 10.27 | 14.33 | 33.40 |
| | 2-7-24 | 2.80 | 4.99 | 7.40 | 1.45 | 0.362 | 0.652 | 20.75 | 1.47 | 2.35 | 1.79 | 13.33 | 15.12 | 9.21 | 30.61 |
| | 4-5-24 | 1.40 | 3.88 | 6.65 | 1.10 | 0.0 | 0.770 | 20.10 | 2.35 | 2.30 | 2.02 | 15.28 | 17.30 | 7.83 | 21.63 |
| Sept. 4 | 11-7-23 | 6.50 | 4.89 | 11.60 | 7.22 | 0.0 | 0.792 | 15.02 | 1.57 | 2.69 | 3.35 | 12.37 | 15.72 | 18.82 | 34.63 |
| | 12-1-23 | 1.88 | 8.60 | 10.80 | 7.07 | 0.0 | 0.435 | 16.55 | 2.05 | 2.45 | 4.06 | 14.39 | 18.45 | 17.89 | 34.85 |
| | 12-22-23 | 2.00 | 7.62 | 10.02 | 7.95 | 0.145 | 0.58 | 17.60 | 2.02 | 2.97 | 3.26 | 13.02 | 16.28 | 18.11 | 36.43 |
| | 2-7-24 | 2.30 | 6.74 | 9.40 | 2.27 | 0.77 | 1.10 | 17.80 | 2.05 | 2.96 | 2.95 | 14.04 | 16.99 | 12.34 | 31.24 |
| | 4-5-24 | 2.20 | 5.50 | 8.10 | 1.92 | 0.00 | 1.32 | 13.70 | 2.20 | 2.50 | 2.73 | 14.92 | 17.65 | 10.02 | 25.03 |
| Sept. 22 | 11-9-23 | 2.80 | 8.69 | 11.70 | 5.80 | 0.362 | 1.32 | 12.30 | 2.15 | 3.61 | 3.44 | 11.74 | 15.18 | 17.86 | 31.84 |
| | 12-1-23 | 2.65 | 11.49 | 14.15 | 7.97 | 0.00 | 1.21 | 13.20 | 2.26 | 3.18 | 3.88 | 13.86 | 17.74 | 22.12 | 36.53 |
| | 12-22-23 | 2.90 | 10.45 | 15.30 | 8.35 | 0.00 | 1.22 | 14.00 | 2.22 | 3.42 | 4.58 | 11.56 | 16.14 | 23.65 | 38.87 |
| | 2-7-24 | 3.90 | 8.26 | 11.45 | 4.77 | 0.995 | 1.15 | 15.35 | 2.30 | 3.50 | 3.88 | 14.92 | 18.90 | 17.21 | 34.70 |
| | 4-5-24 | 3.20 | 4.60 | 10.40 | 4.57 | 0.00 | 0.435 | 13.10 | 3.15 | 3.26 | 3.35 | 14.83 | 18.18 | 15.07 | 28.60 |
| Oct. 5 | 11-9-23 | 5.25 | 7.83 | 13.25 | 1.67 | 0.00 | 1.45 | 12.05 | 2.57 | 3.45 | 3.35 | 9.70 | 13.05 | 14.92 | 28.42 |
| | 12-1-23 | 2.45 | 12.30 | 14.90 | 4.07 | 0.00 | 1.15 | 15.80 | 2.85 | 2.80 | 3.53 | 12.98 | 16.51 | 18.97 | 35.92 |
| | 12-22-23 | 1.88 | 13.97 | 15.80 | 6.40 | 0.00 | 1.55 | 14.40 | 2.17 | 3.11 | 3.79 | 11.11 | 14.90 | 22.20 | 38.15 |
| | 2-7-24 | 3.25 | 9.12 | 12.30 | 2.70 | 0.00 | 0.80 | 14.45 | 2.65 | 3.20 | 2.50 | 14.83 | 17.33 | 15.00 | 30.25 |
| | 4-5-24 | 2.65 | 5.54 | 8.30 | 2.22 | 0.00 | 1.08 | 13.40 | 2.40 | 3.09 | 2.46 | 13.77 | 18.66 | 10.52 | 24.92 |

TABLE 2.—*Showing relative change of carbohydrate and nitrogenous compounds in winter wheat plant crowns at various stages of development during the fall growing and winter dormant season of 1924–25.*

| Date planted | Date collected | Reducing sugars | Sucrose | Total sugar | Dextrins | Soluble starch | Starch | Hemi-cellu-lose | Fats | Total nitro-gen | Pentosans Soluble | Pentosans In-soluble | Pentosans Total | Carbohydrate Water-soluble | Carbohydrate Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | % | % | % | % | % | % | % | % | % | % | % | % | % | % |
| Aug. 22 | 9–12–24 | 1.9 | 1.59 | 3.35 | 1.87 | 0.0 | 0.5 | 14.00 | 2.87 | 3.50 | 3.50 | 14.30 | 16.85 | 5.22 | 19.72 |
| | 9–29–24 | 3.1 | 5.24 | 7.85 | 3.40 | 0.0 | 0.2 | 17.90 | 1.92 | 3.68 | 3.68 | 13.15 | 15.26 | 11.25 | 29.35 |
| | 11–5–24 | 3.25 | 4.42 | 7.70 | 6.32 | 0.0 | 0.8 | 18.25 | 3.12 | 2.91 | 2.91 | 14.92 | 17.47 | 14.02 | 33.07 |
| | 12–2–24 | 6.8 | 5.32 | 12.20 | 3.07 | 0.0 | 0.8 | 15.80 | 2.42 | 2.55 | 2.55 | 12.71 | 15.60 | 15.27 | 31.87 |
| Sept. 3 | 11–5–24 | 3.25 | 5.00 | 8.00 | 8.00 | 0.0 | 0.8 | 15.35 | 2.15 | 2.42 | 2.42 | 15.01 | 17.74 | 16.00 | 32.15 |
| | 12–2–24 | 5.9 | 6.40 | 13.50 | 2.70 | 0.0 | 0.62 | 16.80 | 2.00 | 2.63 | 2.63 | 13.37 | 16.90 | 16.20 | 33.62 |
| Sept. 18 | 11–5–24 | 2.45 | 4.65 | 7.25 | 5.95 | 0.0 | 0.8 | 16.25 | 1.60 | 2.77 | 2.77 | 16.25 | 19.11 | 13.20 | 30.25 |
| | 12–2–24 | 7.7 | 8.31 | 15.80 | 3.20 | 0.0 | 0.62 | 16.10 | 2.25 | 2.87 | 2.87 | 14.39 | 17.03 | 18.00 | 34.72 |
| Oct. 3 | 11–5–24 | 2.05 | 6.17 | 7.70 | 5.87 | 0.0 | 0.57 | 15.50 | 2.47 | 2.98 | 2.98 | 15.01 | 17.96 | 13.57 | 29.07 |
| | 12–2–24 | 7.40 | 9.21 | 16.55 | 2.77 | 0.0 | 0.80 | 14.60 | 1.55 | 2.92 | 2.92 | 12.49 | 15.75 | 19.33 | 34.73 |

The greatest percentages of sucrose and total sugars were found in the crowns of the plants from the fourth date of seeding. This holds true for the analysis on plants grown in 1923 and 1924 as indicated in Figs. 3 and 4 and Tables 1 and 2. For 1923 the order of total sugar

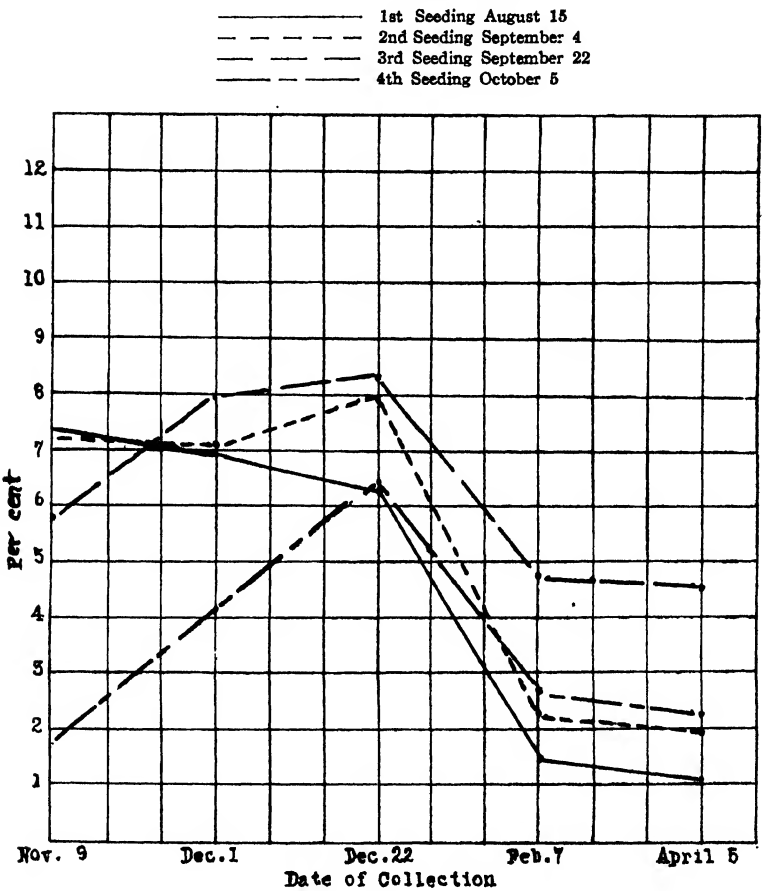


FIG. 5.—Showing percentage of dextrins in wheat plant (crowns) at various dates of collection made during the fall and winter months of 1923 and 1924. Plant collections were made from four dates of seeding.

concentration of the plants from the four dates of seeding ranged as follows: Beginning with the plants of the fourth date of seeding which had the greatest total sugar and sucrose concentration, there was a gradual decrease to the third, second, and first date of seeding in the order given. On December 2, 1924, the first analysis shows a range beginning with the highest sugar concentration in plants from

the fourth date of seeding through the third, second, and first dates, respectively.

The data for dextrin in plants collected in 1923 are presented in Fig. 5 and for 1924 in Table 2. It will be noted that in general the percentage of dextrin was greatest in plants from the third date of seeding. This is followed in order by the percentage of dextrin in plants from the second, first, and fourth dates of seeding, respectively. It is interesting to note that the dextrins in plants from the first date of seeding decreased rapidly after December and were thereafter lower in percentages than they were in plants from any of the other dates of seeding. In 1924 the dextrins increased (Table 2) gradually in plants from the first seeding up to November 5. Samples from the other seedings were not analysed during the same period, hence authentic statements cannot be made concerning these dates. However, there is no doubt that the percentage increase up to November 5 in plants from the second and third seedings was greater than the increase during the same period in plants from the first seeding. This is shown by the fact that on the date mentioned, namely November 5, the percentage of dextrins decreased rapidly for plants of all seedings. At the final analysis on December 2 there was very little difference in the actual percentages of dextrin in plants from the various dates of seeding.

The total water-soluble carbohydrates for 1923 are given in Table 1 and for 1924 in Table 2. This soluble portion includes the total sugars, dextrins, and soluble starch. Data obtained from both years' analyses indicate that the soluble carbohydrate compounds increased until well into December, after which time there was a rapid decrease. The percentage of soluble carbohydrate compounds in plants from the various dates of seeding proceeds in the following order: Beginning with the highest percentage in plants from the third seeding there was a decrease through the fourth, second, and first seeding dates. This order of gradation is very obvious in data obtained from analyses made in 1923 as presented in Table 2. These results do not agree with the results obtained on the samples collected on November 5, 1924. However, one month later (December 2) the above relationship was again similar to the results of analyses made on plants collected the previous year. Attention should be called to the fact that the percentage increase of total soluble carbohydrate substances in plants from the third and fourth dates of seeding was more rapid and continued longer into the fall than the percentage increase of soluble substances in the first and fourth dates of seeding. The graph in Fig. 8 indicates the fact that there was a difference between the

plants from different dates of seeding in their capacity to build and store substances in the crowns and in the rate at which these substances were later respired. Not only was there a difference in the rate of storage and respiration of materials for the plants from the various dates of seeding, but there was also a difference in the time of the season at which the anabolic and catabolic processes occurred. These relationships will be discussed more in detail under "Rate of increase and decrease of the total quantity of carbohydrate compounds in the plant."

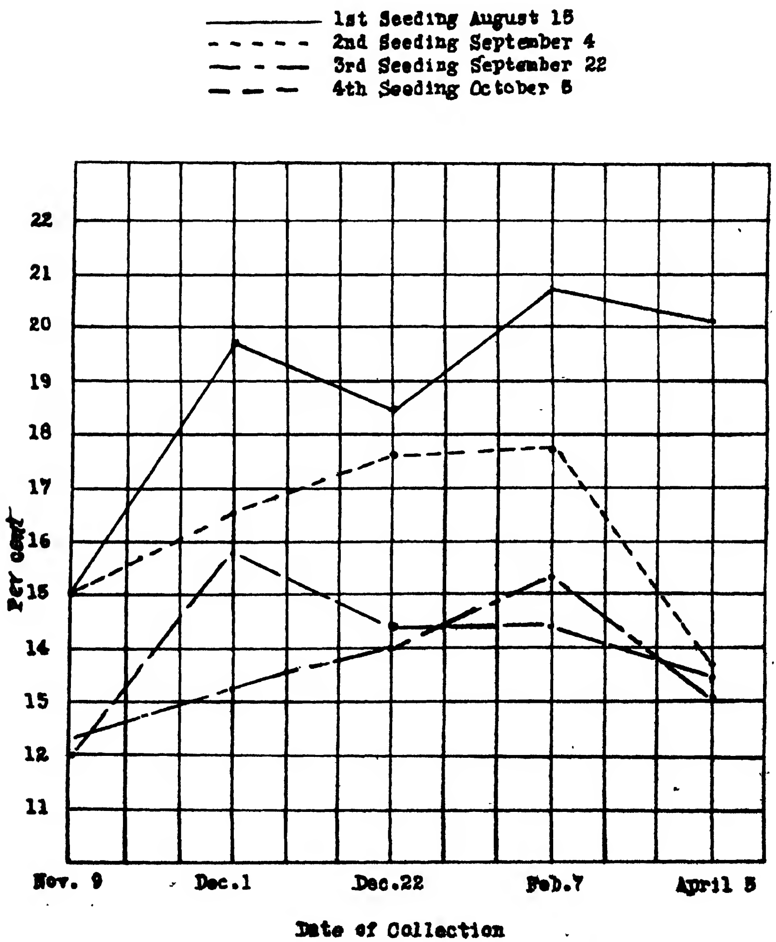


FIG. 6.—Showing percentage of hemicellulose in winter wheat plant (crowns) at various dates of collection made during the fall and winter months of 1923 and 1924. Plant collections were made from four dates of seeding.

The analytical results for hemicelluloses of plants taken from the various test plats seeded in 1923 are plotted in Fig. 6. It will be noted that the percentage of hemicellulose in the plant from the first seeding was very high. Plants from the second date of seeding had the second largest percentage, this being followed by plants of the third and fourth dates of seeding, respectively. It will be noted that in the plants from the fourth date of seeding, the hemicellulose percentage on December 1 was considerably higher than it was in plants from the third seeding, but that this percentage of hemicellulose decreased very rapidly in the plants from the fourth seeding. This, no doubt, is due to the fact that insufficient readily respirable substances had been stored in the crown, and the hemicelluloses were then changed over to glucose and respired as such.

The data on hemicellulose for 1924 are given in Table 2. The percentage of this compound in plants from the first date of seeding gradually increased until its maximum was reached on November 5. It then decreased to a point below the percentage of hemicellulose in the plants of the third date of seeding. It will be noted that on December 2 the percentage of hemicellulose ranged from high to low in plants from the second, third, first, and fourth dates of seeding, respectively. In general, the percentages of hemicelluloses were high when the total soluble carbohydrates were low, and vice versa.

The data on the total carbohydrate compounds in percentage for plants collected in 1923 are indicated in Fig. 7. The relative position of the curves based on the percentage composition in plants from the various dates of seeding corresponds very closely to the relative position of curves on the percentage of soluble carbohydrates of that year.

The percentage of total carbohydrate compounds in plants for 1924 collections are presented in Table 2. The order of percentage composition in plants from the various dates of seeding on December 2 is so very similar to the order obtained in 1923 that no comment need be made. It should be mentioned, however, that on December 2, the total carbohydrate compounds in the plants from the first date of seeding were on the decline, whereas those from the second, third, and fourth are still increasing perceptibly.

## DISCUSSION OF CARBOHYDRATE COMPOUNDS

The data presented on sucrose and total sugars in Tables 1 and 2, clearly conform to the results obtained by various investigators (1, 5, 11, 14, 15, 22, etc.) who found that an increase of these compounds in the plant occurred when the temperature was lowered. It now seems

to be generally conceded that this change of the carbohydrate compounds from the higher polysaccharide substances to the more simple sugars takes place when the temperature is lowered. Whether this is a direct chemical change initiated by the environment, or simply due to the fact that hydrolysis of starch continues at low temperature whereas respiration is decreased and therefore an increased accumulation of sugar occurs, does not seem to be definitely known. To what extent this change aids as a protection to the plant at low temperature is difficult to state, but unquestionably it is not

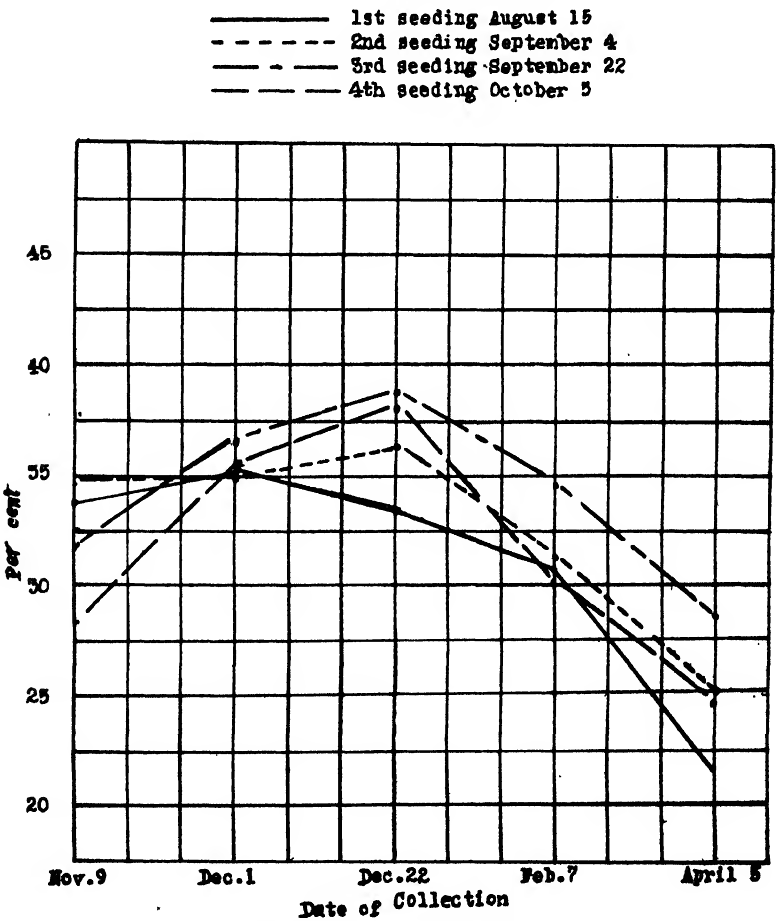


FIG. 7.—Showing percentage of total carbohydrate compounds in winter wheat plant (crowns) at various dates of collection made during the fall and winter months of 1923 and 1924. Plant collections were made from four dates of seeding.

the only means of protection which is afforded the plant in adapting itself to its environment, since as Harvey (8) has pointed out, the hardiness of the plant is obtained before any great change in carbohydrate equilibrium occurs. Schander and Schaffnit (25) conclude that the accumulation of sugar is not an absolute protection against death of the plant by freezing, this having been demonstrated in the case of the sugar beet. It has been shown that the sugar beet freezes readily in spite of the fact that it has a large sugar content. With respect to the protective action of sugar, Gorke (6), Schaffnit (24), Schander and Schaffnit (25), and Newton (19) have shown that the precipitation of protein in the sap may be protected by the addition of sugars. Perhaps the change of the di-, tri-, and polysaccharides to monosaccharides and the taking up of several molecules of water initiates a dehydration effect upon the protein. It may be that this change is worthy of consideration in its relationship to the nitrogen compounds, especially the protein. On the other hand, as noted before, Harvey (8) pointed out that the adaptation to hardiness was much more rapid than a change which could be brought about by increased sugar concentration due to a change in carbohydrate equilibrium.

If we conclude that the percentage of sugar present in the plant tissue is a criterion of hardiness then, basing our conclusions on the extent to which the polysaccharides are changed over to sugars and also on the total amount of sugars present in the plant, the plants from the third and fourth dates of seeding should be the hardiest, and should be in less danger of winterkilling when subjected to a low temperature. From Fig. 1, dealing with the percentage of winterkilling on the various dates of seeding, it will be noted that the greatest percentage of killing occurred on the first and fourth dates. These data, together with the fact noted previously that the plants from the fourth date of seeding had the greatest percentage of sugar in the crowns, indicate clearly that the accumulation of sugar in the plant in itself is not an index to the actual hardiness or lack of hardiness in the plant. It appears, from the above analytical data, obtained in 1923 and 1924, on plants taken from the various dates of seeding, that the greatest amount of sugars (on a percentage basis) accumulated in the young plant or plants from the late dates of seeding. This was due not only to the fact that the seed was planted late in the fall, and that therefore the plants developed under a cool temperature, whereas the older plants did not, but also to the fact that the plants were in a less advanced stage of development and that their cells were smaller and with numerous small vacuoles. This

latter fact, namely, that young plants had a higher sugar content was also noted by Rosa (22) who found that the young leaves of the lettuce plant had a greater sugar content than did those leaves near maturity. Chandler (2), in determining the cold resistance of young and old lettuce plants, found that the young plants were more resistant to cold. This condition did not hold, however, for most of the plants with which he worked.

It would be useless and impossible from the present data available on the carbohydrate relationship of the plant to point to any one factor as the cause of winterkilling. On the other hand, it is evident from the data presented that hardiness cannot be attributed solely to the increase in the percentage of total sugars in the plant.

In studying the rise and fall of the carbohydrate compounds in the wheat plant from various dates of seeding it should be noted that there was first an accumulation of those substances in the crown of the plant. The substances readily usuable for respiration were largely in the form of sugar. The dextrins also accumulated to a great extent, especially in the hardier plants. Very small percentages of starch were found, but this does not bear any relationship to the hardiness of the plant, as suggested by some workers (1). However, the data on the percentage of winterkilling obtained in 1923 on the date of seeding test plats do appear to show some relationship to the percentage of dextrins in the plants (Fig. 4). The above compounds, i.e., the starches and dextrins, may be looked upon as reserve materials accumulating in the crowns of the plant, to be changed later in the season into simple forms of sugar and possibly respired as such. Even the hemicellulose may undergo hydrolysis as in the case of plants from the fourth date of seeding. It may be that the depletion of the hemicellulose also greatly reduces the structural material of the young plant, and that therefore the actual structure of the plant becomes inadequate for the severe environmental conditions to which it is subjected.

By a study of the graphs in Fig. 7 and the explanation given therewith, it will be noted that the relative percentages of total carbohydrate compounds of the plants from the various dates of seeding were different. The total percentage of the various compounds, accumulated in the crown before active respiration exceeded photo synthesis, differed in plants for the different dates of seeding. This evidence is more clearly brought out in Tables 3 and 4. These data were figured on the percentage increase and decrease of weight in grams of the relative carbohydrate compounds in the plant, based on the first collection. Table 3 shows that the greatest increase in growth, based

on the increase of dry weight, to December 1, was made by plants from the first date of seeding. These plants, however, began to lose weight more rapidly thereafter than the carbon assimilation capacity of the plant could build it up. This relative early decrease in weight was presumably due to two factors, i.e., jointing and stooling. It is apparent from Table 3 that the plant from the first date of seeding at the above stage of development had changed from an active storage state to one of active growth. Whether jointing initiated active growth or whether growth brought about jointing, cannot be stated, but it is evident that this active growth and this increased respiration decreased the compounds stored in the crown of the plant.

Grantham (7) has shown that the number of buds and stolons produced on the plant depends upon the time of seeding in the fall. The plants from the early seedings have a greater number of buds or stolons than the plants from the late seedings. It seems logical to assume, therefore, that these embryonic buds must respire, and this together with the energy used in the process of jointing, as noted previously, leads to an early and rapid decrease in the weight of the crown. It is not at all improbable that taking the plant as a whole there would have been an actual increase in total weight, but on the crown basis, the storage organ of the wheat plant, the weight actually decreased during this time.

Continuing with the percentage increase and decrease in weights of plants for the various dates of seeding, particular attention should be placed on the curve obtained for plants from the fourth date of seeding. It will be noted that there was only a very small increase in weight per plant after the first collection made on November 9 (Table 3). There was an increase of 6% followed by a rapid decrease to April 5, on which date the plant crowns were 40% less in weight than they were on November 9 of the previous year. The percentage increase in total weights of plants from the second and third dates of seeding continued up to December 22, after which date it fell off more or less gradually until April 5. It will be seen that the accumulation in weight per plant from the second, third, and fourth seedings continued longer into the winter than did the increase in weight of plants from the first seeding, also that the decrease in plants from the second and third seedings was not so great as was the decrease in weight of plants from the first and fourth seeding.

If we make comparisons of the increase and decrease of the plants from the various dates of seeding based on the total quantity of compounds in the plant, such as total carbohydrates and total water-soluble carbohydrates, we find that the percentage increase and

**TABLE 3.**—*Showing absolute quantity of carbohydrate compounds (in grams) and the percentage of increase or decrease during the fall and winter season of 1922–23.**

| Date of seeding | Date collected | Total weight per plant, grams | Gain in weight % | Weight in grams on the basis of 100 plants: Sucrose | Total sugars | Dextrins | Total soluble carbohydrates | Gain or loss in soluble substance % | Weight in grams on the basis of 100 plants: Hemicellulose | Total carbohydrates | Gain or loss of total carbohydrate substance % | Weight of total pentosans in grams per 100 plants | Gain or loss of total pentosans % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Aug. 15 | 11–9–23 | 0.14162 | —— | 0.4432 | 1.4443 | 1.0435 | 2.4882 | —— | 2.1664 | 4.76692 | —— | 2.6068 | —— |
| | 12–1–23 | 0.2424 | 71.18 | 0.6641 | 1.9392 | 1.6725 | 3.6117 | 45.10 | 4.7874 | 8.52036 | 78.70 | 4.0505 | 55.38 |
| | 12–22–23 | 0.2187 | 54.44 | 1.9585 | 1.6839 | 1.3821 | 2.1339 | 25.90 | 4.0240 | 7.3045 | 53.30 | 2.246 | —13.80 |
| | 2–7–24 | 0.1506 | 6.35 | 0.6008 | 1.1144 | 0.21837 | 1.3870 | —42.25 | 3.1249 | 4.6009 | — 3.27 | 2.2770 | —12.65 |
| | 4–5–24 | 0.1495 | 5.57 | 0.5800 | 0.9941 | 0.1644 | 1.17058 | —52.05 | 3.0049 | 2.23368 | —32.16 | 2.5863 | —0.786 |
| Sept. 4 | 11–9–23 | 0.07122 | —— | 0.3482 | 0.8261 | 0.51420 | 1.3406 | —— | 1.0690 | 2.4663 | —— | 1.11957 | —— |
| | 12–1–23 | 0.09411 | 32.16 | 0.8093 | 1.0165 | 0.6653 | 1.6817 | 25.44 | 1.5575 | 3.27973 | 32.90 | 1.73630 | 55.08 |
| | 12–22–23 | 0.10730 | 50.70 | 0.8176 | 1.0751 | 0.85303 | 1.9432 | 44.95 | 1.8884 | 3.90893 | 58.30 | 1.7468 | 56.03 |
| | 2–7–24 | 0.08028 | 12.64 | 0.5410 | 0.7546 | 0.18223 | 0.9906 | —26.17 | 1.4289 | 2.50794 | 1.69 | 1.3639 | 21.83 |
| | 4–5–24 | 0.07785 | 9.26 | 0.4281 | 0.6305 | 0.14946 | 0.78005 | —41.80 | 1.0665 | 1.9485 | —21.00 | 1.3740 | 22.69 |
| Sept. 22 | 11–9–23 | 0.02634 | —— | 0.2291 | 0.3088 | 0.15294 | 0.47096 | —— | 0.3243 | 0.83962 | —— | 0.40029 | —— |
| | 12–1–23 | 0.03754 | 42.35 | 0.4313 | 0.5311 | 0.29919 | 0.83038 | 76.31 | 0.4955 | 1.3713 | 63.30 | 0.66595 | 66.36 |
| | 12–22–23 | 0.04058 | 53.88 | 0.4240 | 0.62087 | 0.33884 | 0.95971 | 103.77 | 0.56812 | 1.57734 | 87.86 | 0.65496 | 63.62 |
| | 2–7–24 | 0.03150 | 19.93 | 0.2601 | 0.36067 | 0.15025 | 0.54211 | 17.44 | 0.48352 | 1.09305 | 30.10 | 0.59535 | 48.72 |
| | 4–5–24 | 0.03020 | 14.56 | 0.1389 | 0.3140 | 0.13801 | 0.45511 | — 3.365 | 0.39562 | 0.86372 | 2.87 | 0.54903 | 37.15 |
| Oct. 5 | 11–9–23 | 0.01446 | —— | 0.1132 | 0.1915 | 0.02414 | 0.21574 | —— | 0.17424 | 0.41095 | —— | 0.18870 | —— |
| | 12–1–23 | 0.01476 | 2.07 | 0.18154 | 0.2199 | 0.06007 | 0.27990 | 29.73 | 0.23320 | 0.53017 | 26.10 | 0.24368 | 29.13 |
| | 12–22–23 | 0.01520 | 6.50 | 0.2123 | 0.2401 | 0.09728 | 0.33744 | 56.41 | 0.21888 | 0.57988 | 41.10 | 0.22648 | 20.021 |
| | 2–7–24 | 0.01096 | —24.20 | 0.0999 | 0.1348 | 0.02959 | 0.16425 | —23.86 | 0.15834 | 0.33154 | −19.30 | 0.18988 | 0.5829 |
| | 4–5–24 | 0.00865 | —40.47 | 0.0479 | 0.0717 | 0.01920 | 0.09099 | —57.82 | 0.01159 | 0.21555 | —47.50 | 0.16140 | −14.46 |

*Percentages based on dry weight of first date of sampling.

TABLE 4.—*Showing the total quantity of carbohydrate compounds in grams and percentage of increase or decrease during the fall and winter season of 1924.**

| Date of seeding | Date collected | Total weight per plant, grams | Gain in weight % | Weight in grams on the basis of 100 plants: Sucrose | Total sugars | Dextrins | Total soluble carbo-hydrates | Gain in soluble sub-stance % | Weight in grams on the basis of 100 plants: Hemi-cellulose | Total carbo-hydrates | Gain of total carbo-hydrate sub-stance % | Weight of total pento-sans in grams per 100 plants | Gain of total pento-sans % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Aug. 22 | 9-12-24 | 0.01715 | —— | 0.0272 | 0.0574 | 0.0320 | 0.0894 | —— | 0.2399 | 0.3380 | —— | 0.6268 | —— |
| | 9-29-24 | 0.7180 | —— | 0.37623 | 0.5636 | 0.2441 | 0.8077 | —— | 1.2852 | 21.0733 | —— | 1.0956 | —— |
| | 11-5-24 | 0.2283 | —— | 1.0090 | 1.7579 | 1.4428 | 3.2007 | —— | 4.1664 | 7.5490 | —— | 3.9884 | —— |
| | 12-2-24 | 0.2790 | 22.20 | 1.4842 | 3.4038 | 0.8565 | 4.2603 | 33.10 | 4.4080 | 8.8917 | 17.78 | 4.3524 | 9.124 |
| Sept. 3 | 11-5-24 | 0.08116 | —— | 0.4058 | 0.6492 | 0.6492 | 1.2985 | —— | 1.2458 | 2.6092 | —— | 1.4397 | —— |
| | 12-2-24 | 0.1123 | 27.72 | 0.7187 | 1.5160 | 0.3032 | 1.8192 | 40.10 | 1.8866 | 3.7755 | 63.73 | 1.8978 | 31.81 |
| Sept. 16 | 11-5-24 | 0.0307 | —— | 0.1422 | 0.2187 | 0.1795 | 0.3982 | —— | 0.4902 | 0.9126 | —— | 0.5765 | —— |
| | 12-2-24 | 0.06318 | 109.001 | 0.5250 | 0.9982 | 0.2021 | 1.1372 | 185.58 | 1.0171 | 2.1936 | 140.36 | 1.0759 | 86.64 |
| Oct. 3 | 11-5-24 | 0.0185 | —— | 0.1142 | 0.1425 | 0.1086 | 0.2511 | —— | 0.2869 | 0.5377 | —— | 0.3322 | —— |
| | 12-2-24 | 0.0338 | 82.70 | 0.3112 | 0.5593 | 0.09362 | 0.6533 | 160.19 | 0.4934 | 1.1738 | 118.30 | 0.5323 | 60.23 |

*Percentages based on dry weight of first date of sampling.

decrease varied with the date of seeding. Fig. 8 shows the percentage increase and decrease based on the soluble carbohydrate substances in plants from the four dates of seeding. Beginning with the plants from the date of seeding having the greatest percentage increase of substances, we find that plants from the third date of seeding ranked highest, followed by those from the fourth, second, and first, respectively. The total water-soluble carbohydrate substances in plants from the first seeding was exceedingly low throughout the winter season due, no doubt, to factors mentioned previously. Though the increase and decrease of total water-soluble carbohydrate substances in plants from the fourth date of seeding ranked next to the water-soluble carbohydrate substances in the plants from the third seeding date, it should be noted that on April 5 the quantity of substances had decreased to a point much below that of the third date and was on a par with the plants from the first date of seeding.

In all the above instances the weight of the crowns, or the total quantity of carbohydrate substances, had decreased to a greater extent in the plants from the fourth and first seeding than that of the plants from the second and third seeding, respectively.

It seems evident that this increase and decrease of stored material should bear an important relation to the hardiness of the plant. Fig. 1 shows the percentage of winterkilling of the plants from the various dates of seeding. The greatest percentage of killing took place in the fourth and first dates of seeding followed in order by the second and third. This indicates that there was a direct relation between the increase and decrease of the total quantity of carbohydrate compounds in the plant during the entire season and its resistance to cold. Such correlations also exist to a large extent with respect to increase and decrease in actual percentage of total carbohydrates in plants from the four dates of seeding (Table 3).

It seems probable from the above data, that winterhardiness, or rather, the survival of the plant during low temperatures, may not depend upon the composition of the plant at any one given date or period, but rather depends upon the metabolic processes going on in the plant during the entire winter dormant season. It is known that the action of water in the plant and the firmness with which this water is bound in the tissue depends upon the imbibitional powers of the hydrophyllic collodial substances in the tissue (19) and that this affords a measure of protection to the plant from injury through low temperatures. Other factors and forces are operating, possibly simultaneously, to bring about the hardened condition of the plant. Among these may be mentioned osmotic forces and actual protection against

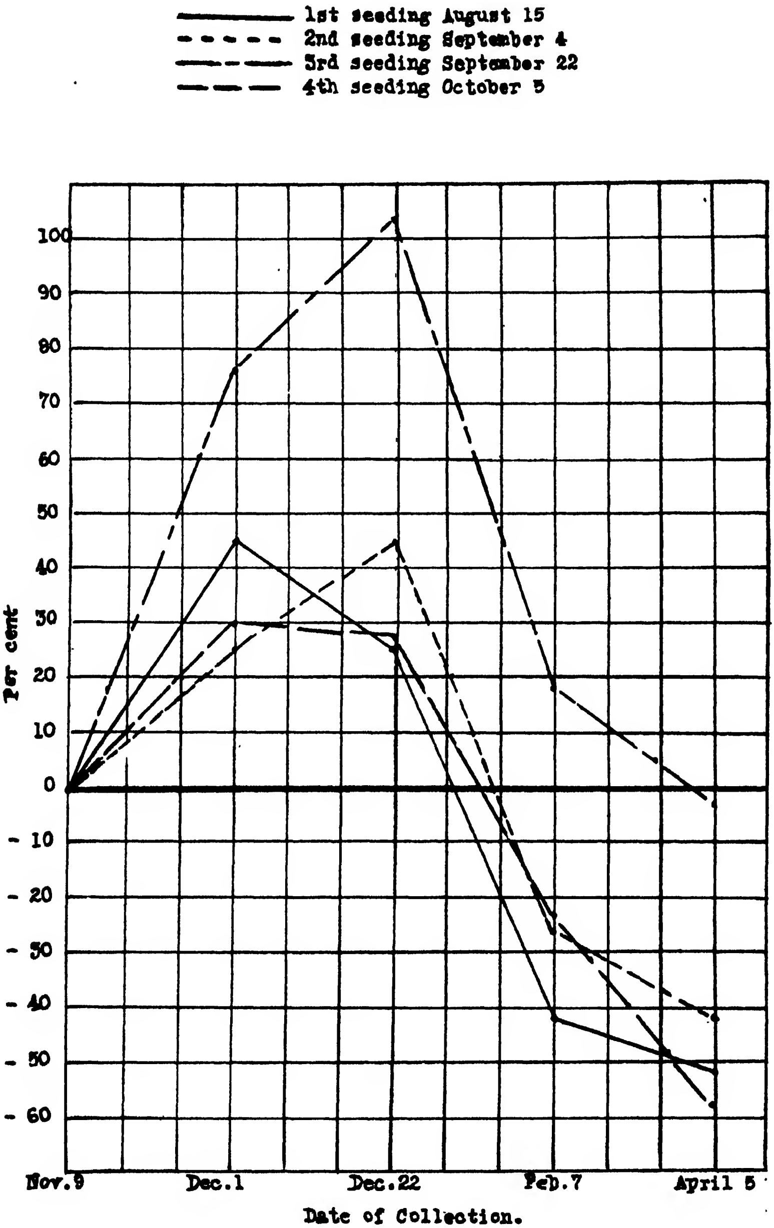


FIG. 8.—Showing percentage increase and decrease of water-soluble carbohydrate compounds in the winter wheat plant (crowns) during the fall and winter of 1923 and 1924. Plant collections were made from four dates of seeding.

protein precipitation, and lastly reserve food materials which may eventually take into account all the other forces combined. Certainly the reserve food materials would aid the plant to begin vigorous growth in the spring. Such a situation or condition may well exist in the plant in the fall of the year, but the status in the plant is very subject to change, as indicated in data presented above. It is doubtful if these various forces would continue to persist as substances are being respired or lost through leaching. It may well be that the high percentages of winterkilling in the fourth date of seeding was due, among other causes, to an insufficient quantity of reserve materials which would have helped to protect the plant against cold, especially during the latter part of the winter season, and to supply the embryonic shoot with nourishment on which it could continue growth early the following spring.

### PENTOSANS

It is pointed out in a subsequent paper (9) that osmotic measurements made by the depression of the freezing point are not indices of the degree of hardiness of the plant. This lack of correlation was due, among other things, to the fact that the nitrogenous and carbohydrate compounds in the tissue were released with greater or less difficulty on extraction of the sap, depending upon the stage of plant development. It is doubtful, on the other hand, if substances capable of increasing osmotic pressure would show specific correlation of osmotic pressure, and the ability of the plant to survive the winter. Rosa (23) suggests that the apparent increase in sap concentration is simply an accompaniment in hardiness rather than a cause of increased hardiness.

The power of imbibition of hydrophyllic colloids has been investigated by Rosa (23). He came to the conclusion that the imbibing power of the plant was largely dependent upon the pentosans present. In the groups of vegetable plants with which he worked and which were capable of considerable hardening to cold, the increase in total pentosan content upon hardening was largely an increase in the hot-water-soluble fraction. Newton (19) found that while wheat leaves increased progressively in pentosan content during the hardening process in the fall and winter, there could be found no correlation with hardiness and pentosan content for any one collection, the non-hardy varieties in some instances having as large or greater pentosan content than the hardy varieties.

In the experiments here detailed the pentosan content, both soluble and insoluble, was determined on plants from four dates of seeding collected in the field during the fall and winter of 1923–24. The data are presented in Tables 1 and 2, and plotted in Fig. 9. For

1923 (Fig. 9) the soluble pentosan was greatest in plants from the third date of seeding, followed in order by the second, fourth, and first seedings. The data on soluble pentosans, given in Table 2, show some correlation with the hardiness of the plant, but the percentage

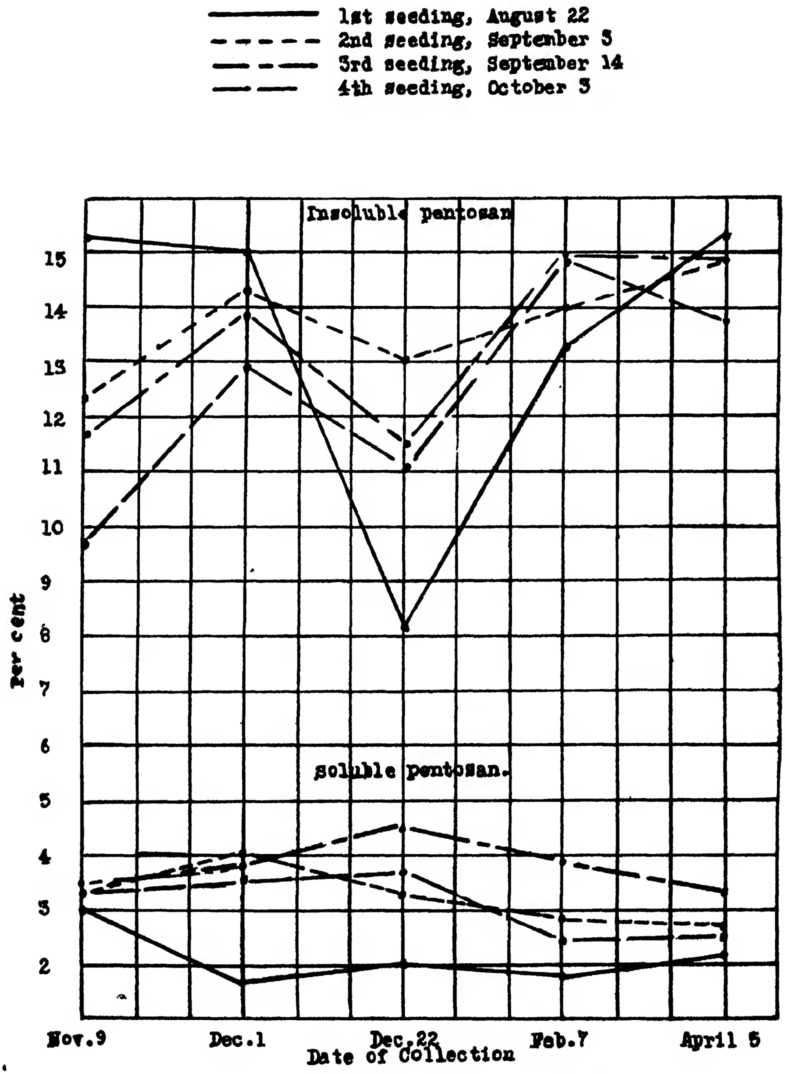


FIG. 9.—Showing percentage of soluble and insoluble pentosans in winter wheat (crowns) at various dates of collection made during the fall and winter months of 1923 and 1924. Plant collections were made from four dates of seeding.

differences were so small that they cannot be regarded as significant. The data on insoluble pentosan in plants from the four dates of seeding (Tables 1 and 2) show absolutely no relation to winter-hardiness.

The data on total pentosans for plants from the various seedings made in 1923 are given in Fig. 10. It will be noted that the total

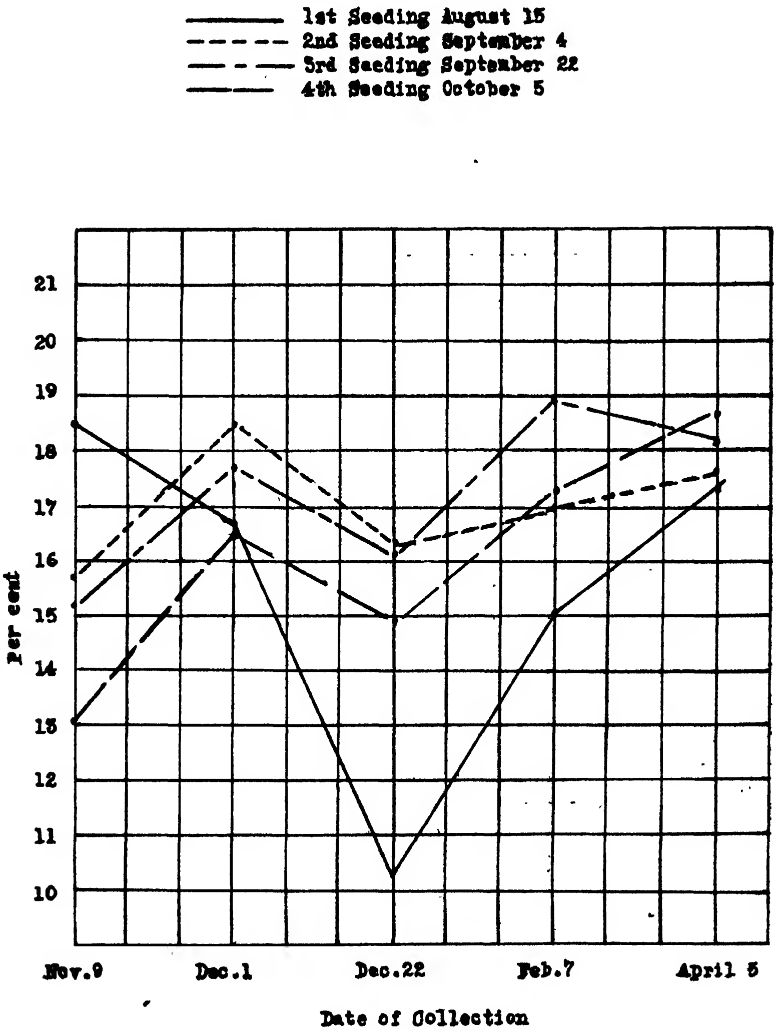


FIG. 10.—Showing percentage of total pentosans in winter wheat (crowns) at various dates of collection made during the fall and winter months of 1923 and 1924. Plant collections were made from four dates of seeding.

percentage fluctuates considerably throughout the year, increasing slowly from November 9 to December 1, with the exception of those plants from the first seeding which were on the decline, and then decreasing gradually to February 7 and thereafter remaining more or less constant the remainder of the winter. The pentosan content of plants from the first date of seeding decreased from 15.3% on November 8 to 8.21% on December 22, and thereafter showed a continual rise up to 15.28% on April 5. These fluctuations are not accounted for. The 1924 data are given in Table 2. The total pentosan content of the plants from the various seedings in this year also fluctuated greatly. The results of the pentosan analysis made on samples of plants collected from the four dates of seeding on November 5 were 1.0 to 3.0% higher for each date of seeding than they were on December 2. At the time of the November 5 collections the upper 6 inches of soil had a moisture content of 8%, whereas on December 2 it had a moisture content of 30%. It appears, therefore, that the hexose carbohydrates are changed over to the pentose forms under arid conditions. In this year, the results of total pentosans for collections of plants made on December 2 are correlated with winterhardiness, the highest content being obtained in the plants from the third date of seeding.

These results of total pentosan content taken from all the determinations are presented here in a general way to show some correlation with the degree of hardiness and percentage of winterkilling, but it cannot be claimed with any degree of exactness that pentosan content is a specific index of hardiness. The highest percentages of pentosan, however, are associated with the favorable seeding dates, though it is not believed that this is the factor responsible for the added hardiness. It is probably better to judge the increased pentosan content as an accompanying factor rather than a direct case of hardiness.

## RELATION OF NITROGENOUS AND PROTEINACEOUS COMPOUNDS OF PLANTS TO WINTERKILLING

A discussion of the literature pertaining to the effect of cold on the nitrogen and proteins in the plant is not given here, because this has been well reviewed by Schander and Schaffnit (25), Chandler (2), Rosa (23), and Newton (18, 19). It appears from a survey of this literature that the effect of cold tends toward protein precipitation. How this is brought about when the cell freezes is not clear, but the increased pH concentration, increased salt concentration, and cell dessication are factors concerned. In the present investigation, along with the carbohydrate changes of the plant during the winter months, a study was also made of the total nitrogen in the plants

during two seasons and also of the total soluble nitrogen and heat-coagulable protein nitrogen during one season. The results are given below.

Plant crown samples were taken from the various dates of seeding plats during 1923–24. During the first year the tissue was collected as already described. It was not planned to make any soluble extracts

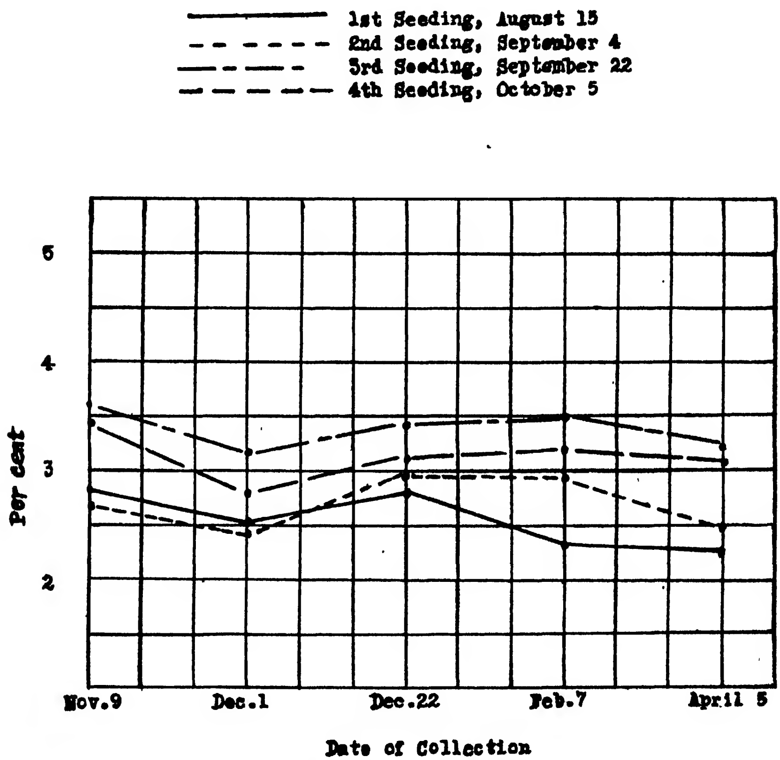


FIG. 11.—Showing percentage of total nitrogen in winter wheat plants at various times of analysis during the fall and winter of 1923 and 1924. Analyses made on plants from four dates of seeding.

on these samples. During the second season, 1924–25, plant tissue was collected as in the previous season, but at the same time samples for the determination of nitrogen distribution were taken.

The data on total nitrogen for both winter seasons are given in Tables 1 and 2. The results for 1923 are plotted in Fig. 11. It is evident from these data that there was no particular change in the percentage concentration during the winter season. In general, the percentage of total nitrogen in the plants from the different dates of

seeding in 1923 ranged from high to low as follows: Third, fourth, second, and first seedings, respectively.

The data for total nitrogenous compounds for plants on the date of seeding tests for 1924 are presented in Table 2. Here again it will be noted that there was no particular difference in percentage concentration during the fall season. The plants from the first date of seeding showed a general decrease in nitrogen from 3.50 to 2.54%. No collections were made on September 12 and 29, 1924, of plants from the second, third, and forth dates of seeding, hence a comparison cannot be made with the analytical data of plants for these dates with the analytical result of plants from the first date of seeding. There was no appreciable fluctuation in the percentage of total nitrogen of the plants from the three dates just mentioned. The data on the total nitrogen composition of plants from the various dates of seeding indicate that a plant in the early period of growth has a larger percentage of nitrogenous substances than it does at a more mature stage. In other words, according to the 1924 data (Table 2), the percentage of total nitrogen in the crown of the wheat plant decreases as the plants develop. However, in the plants from the second and third dates of seeding the percentage of nitrogen shows further increase. The very high total nitrogen in some of the very young plants may be partially explained on the basis of the reserve material which the young shoot was able to obtain from the old endosperm. This reserve material naturally decreases as the shoot becomes older.

## DISTRIBUTION OF NITROGEN

The distribution of nitrogen in the crown of the wheat plant was determined in a series of collections made from the date of seeding tests in 1924. The data from these determinations are presented in Table 5. It will be noted that the soluble nitrogen increased as the season advanced. This was not due to the fact that the plants were older, but because of differences in the time of season in which they were grown, since the size of the plants analysed from the fourth date of seeding on November 8 and on December 8, 1924, corresponded to the size of the plants analysed from the first seeding on September 8, 1924, and September 26, 1924, yet the latter two analyses show a lower water-soluble nitrogen proportion than do the former.

It will be noted from Table 5 that the percentages of total nitrogen are given together with the water-soluble fraction and soluble coagulable nitrogen. The percentage of soluble protein as indicated in Table 5 on analytical results of plants from the first date of seeding first increased from 53.4 to 65.5%, and then decreased to 33.6% in

TABLE 5.—*Nitrogen distribution at various intervals during the fall of 1924 in winter wheat plant crowns taken from four dates of seeding.**

| Date of seeding | Date collected | Total nitrogen | Total water-soluble nitrogen | Protein nitrogen | Nitrogen in filtrate | Total nitrogen soluble | Soluble nitrogen precipitated |
|---|---|---|---|---|---|---|---|
| | | % | % | % | % | % | % |
| August 15 | 9-8-24 | 3.50 | 1.42 | 0.67 | 0.76 | 40.3 | 53.4 |
| | 9-26-24 | 3.68 | 2.23 | 1.41 | 0.81 | 60.6 | 63.2 |
| | 11-7-24 | 2.91 | 2.09 | 1.37 | 0.55 | 71.8 | 65.5 |
| | 11-8-24 | 2.95 | 2.05 | 0.92 | 1.03 | 70.44 | 44.9 |
| | 12-8-24 | 2.06 | 1.66 | 0.559 | 1.098 | 80.58 | 33.61 |
| September 4 | 11-8-24 | 2.42 | 1.83 | 0.53 | 1.38 | 75.60 | 29.00 |
| | 12-8-24 | 2.63 | 2.29 | 0.651 | 1.37 | 87.07 | 28.43 |
| September 22 | 11-7-24 | 2.84 | 1.58 | 1.13 | 0.65 | 56.00 | 71.50 |
| | 11-8-24 | 2.77 | 2.07 | 0.54 | 1.52 | 74.70 | 26.10 |
| | 12-8-24 | 2.87 | 2.24 | 0.64 | 1.57 | 80.00 | 28.57 |
| October 5 | 11-8-24 | 2.98 | 2.06 | 0.73 | 1.41 | 69.10 | 35.40 |
| | 12-8-24 | 3.12 | 2.35 | 0.95 | 1.35 | 73.30 | 40.40 |

*The November 7, 1924, seedings were analyzed before freezing. The November 8, 1924, seedings were analyzed after tissue had frozen in the field.

the case of plants having been frozen while still in the soil. The analytical data from the collections made on November 7 and December 8, 1924, of plants taken from the second, third, and fourth dates of seeding convey results similar to the above.

From these results, therefore, it appears that the protein molecule is very unstable and that the lowering of the temperature has a stabilizing effect on the molecule. This change of form may be a protective action against precipitation, and this capacity to change varies with the stage of plant development.

## UNSTABILITY OF THE PROTEIN MOLECULE ON THE FREEZING OF PLANT TISSUE

An effort was made to determine what effect freezing had upon the normal plant. This work was done with plants grown on the field test plats. In the fall of 1924 it was convenient to make two determinations of the nitrogen distribution of the wheat plant on two different dates of seeding. It so happened that one series of nitrogen determinations was made on November 7, 1924, on a cool day before the freezing occurred. Another series of nitrogen distribution determinations was made on similar plants the following day, November 8, after a severe freeze; a freeze so severe that the leaves of the plants were frozen stiff and the soil frozen to a depth of 2 inches. Samples of

plants were taken from the first seeding, namely, August 22, which is known from practical experience to lack hardiness, and from the third date of seeding plat planted September 4 which is known to be hardy. This evidence is also brought out in Fig. 1 which gives the percentages of winterkilling from the various dates of seeding over a period of three consecutive years, i.e., 1922 to 1925.

The data for the above analyses are presented in Table 6. They show that 71.8% of the nitrogen in plants from the first seeding was soluble when analyzed or collected before frost, while after freezing 70.44% was soluble. Comparing this with the percentage of nitrogen which was soluble in plants for the third date of seeding, collected before frost, it will be found that 56.0% was soluble, whereas, after the plants were frozen 74.7% was soluble. These figures indicate that there was relatively little change due to freezing in the plants from the first seeding. The figures show a decrease of 1.36% of soluble nitrogen based on the total, whereas for plants from the third seeding there was an increase of 18.7% in the soluble nitrogen due to freezing.

TABLE 6.—*Showing the nitrogen distribution of plants from two dates of seeding, before and after freezing of the tissues.**

| Date of seeding | Date of analysis | Total nitrogen % | Total Water-soluble nitrogen % | Protein nitrogen % | Nitrogen in filtrate % | Total nitrogen soluble % | Soluble nitrogen precipitated % |
|---|---|---|---|---|---|---|---|
| Aug. 15.... | 11-7-24 | 2.91 | 2.09 | 1.37 | 0.55 | 71.80 | 65.5 |
| Aug. 15.... | 11-8-24 | 2.85 | 2.05 | 0.92 | 1.03 | 70.44 | 44.9 |
| Sept. 22.... | 11-7-24 | 2.84 | 1.58 | 1.13 | 0.65 | 56.00 | 71.5 |
| Sept. 22.... | 11-8-24 | 2.77 | 2.07 | 0.54 | 1.52 | 74.70 | 26.1 |

*The November 7 samples were analyzed before freezing. The November 8 samples were analyzed after freezing. The plants from the first date of seeding were more subject to winterkilling than those from the third date of seeding.

If attention is focused on the quantity of material which precipitated through the action of heat, it will be found that 65.5% of the soluble substances in the plants from the first seeding precipitated before the tissue was frozen. This decreased to 44.9% after freezing had occurred. The amount of soluble nitrogen precipitated in plants of the third seeding before freezing was 71.5%, whereas after freezing only 26.1% precipitated. Comparing the above results, it is found that, due to freezing, the precipitable material of the soluble nitrogen decreased 20.6% in the plants of the first seeding and 45.4% in plants from the third seeding. Cognizance should also be taken of the difference in the percentage of the simpler forms of nitrogen which were found before and after freezing in the plants from the two dates of

seeding. It will be seen that after freezing, in plants from both dates of seeding, that the simpler forms of nitrogen had greatly increased, but that the increase was much more pronounced in plants from the third date of seeding.

The above results are by no means conclusive, more determinations must be made, and these results verified before definite statements can be made, but the results as obtained under the above conditions show that a rapid change was effected in the protein molecule due to the freezing. This change led to a greater amount of soluble nitrogenous substance and the rate at which these changes took place varied with the stage of development of the plants. The protoplasm of the plants of the hardier dates of seeding seems to have had a greater capacity of adjusting itself to its environment and this greater capacity of adjusting partially, at least, depended upon the relative change of the nitrogenous materials over into a soluble form which was less readily precipitable.

There appears to have been a rapid change in the protein molecule, tending towards an unprecipitable form when the temperature was decreased by freezing. This change, as noted above, varied with the plant, depending upon the time of seeding. It was noted also that plants from the better dates of seeding had much less precipitable material after freezing than did those plants from the less favorable dates. The capacity and rate of change of the nitrogenous substances over to the more simple forms, such as the amino acids (and diamino acids), is also very striking and worthy of attention. Whether the physiological significance of the increase in the simpler forms of nitrogen, brought about by protein splitting, is an adaptation to prevent protein precipitation, or, as Newton (19) suggested, yields active agents in producing optimum hydration of biocolloids, is not known. It may not be improbable that this change of nitrogenous material over to the more simple forms of nitrogen, such as amino and diamino acids, initiates a buffering effect on the protoplasm of the cell. This buffering effect might tend to prevent changes commonly brought about by increased acid or salt concentration, as has been found by some investigators to take place in the cell upon freezing. The writer has investigated the buffer capacity of different plant saps by electrometric titration. He was unable to find any correlation of hardiness to the buffer capacity in the plant sap, yet the results were by no means conclusive. Further investigations along this line may prove valuable.

## SUMMARY

1. Changes in the composition of the crown of the wheat seedling were studied during two consecutive winter seasons, 1923–24 and 1924–25. Plants were taken from three dates of seeding test plats. Seedings were made on or close to the following dates: August 15, August 31, September 21, October 6, and October 19. The order of mortality due to winterkilling, from high to low, for three years, 1922 to 1925, was as follows: October 19, October 6, August 12, August 31, and September 21.

2. In general there seemed to be a positive correlation between the total soluble carbohydrate compounds and better dates of seeding or winterhardiness for the year 1923. The September 21 seeding, the best date of seeding, showed in 1923, particularly, the greatest percentage of total sugars as well as total carbohydrate compounds. However, for the two years' results, winterhardiness could not be attributed to the hexose carbohydrate compounds alone.

3. The total nitrogen compounds remained about the same throughout the winter months, being somewhat higher in the young plants than in the older plants.

4. The water-soluble nitrogen and soluble nitrogen which is coagulable by heat increased during the fall months as the temperature decreased. The soluble nitrogen which is coagulable was found to increase with the lowering of the temperature to the freezing point after which it greatly decreased.

5. The percentage of water-soluble nitrogen which is coagulable was greatest for the favorable dates of seeding, before the plants were frozen, but after freezing occurred the coagulable nitrogen was much less for plants from the favorable than from the unfavorable seedings.

6. The plants from the most favorable dates of seeding have a greater capacity of changing the protein nitrogen from a precipitable to a nonprecipitable form.


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# COMPARATIVE RANGES OF ADAPTATION OF SPECIES OF CULTIVATED GRASSES AND LEGUMES IN OKLAHOMA[1]

K. H. Klages[2]

## INTRODUCTION

The location of our great and rather well-defined forage provinces, such as the bluegrass, timothy, orchard grass, red clover, white clover, or bermuda producing regions, are determined primarily by the degree of adaptation shown by the respective grasses and legumes to prevailing climatic conditions. Soil factors, while having local effects on the utilization of specific forage plants, do not exhibit the regional influences of the climatic factors. The distribution of specific forage plants is not as general as that of the cereal crops. This is to be expected, since perennial forage plants must survive through the favorable as well as the unfavorable portions of the year. Grasses and small-seeded legumes produce plants very delicate during their early phases of development. Such plants are consequently not well adapted for a struggle against an unfavorable environment. The production of forage plants slow to establish themselves becomes especially hazardous in regions with severe climates. Yet, from an experimental standpoint, the specific ranges of adaptation of such plants may best be determined in such regions. Since the great forage provinces of the northeastern states do not extend as far to the west or to the south nor many of the forage-producing regions of the southern states as far north as north-central Oklahoma, the Oklahoma Experiment Station promised to offer a favorable location for a study of specific ranges of adaptation of northern and southern forage plants.

## SELECTION OF FORAGE CROPS FOR CENTRAL OKLAHOMA

The producer in the eastern more humid sections of the United States has a great variety of forage plants to select from in the choice of grasses and legumes for his meadows and pastures. In the Great Plains area, and especially in the southern portion of this area, the number of cultivated forage plants to be chosen from becomes exceedingly limited. Due to the rigor and irregularity of climatic factors, only the more hardy plants can survive. To complicate the

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problem further some of the plants, such as Johnson grass or bermuda especially adapted to endure the at times dry periods and high temperatures, have characteristics making them unfit for general recommendation. These plants, due to the difficulties encountered in their eradication, cannot be recommended for areas to be cultivated in the near future. Thus the list from which selections could be made becomes still shorter. In the extreme western portions of this area the growing of cultivated perennial grasses is entirely out of question; their places are taken by annuals or by such native grasses as may be found. Such crops as alfalfa and sweet clover, due to their extensive root systems, can endure greater climatic extremes than the perennial grasses, especially, as will be pointed out later, where soil conditions favor them.

Before treating specific forage crops it may be well to consider the distribution of convenient groups of such crops. This is best done by taking account of the natural vegetation of the region.

## GROUPS OF FORAGE PLANTS IN OKLAHOMA

The hay-producing forage plants of Oklahoma and of other states of the central and southern Great Plains area may conveniently be grouped into five classes, *viz.*, (a) alfalfa; (b) cultivated perennial grasses and legumes, such as timothy, orchard grass, redtop, red clover, alsike clover, etc.; (c) native grasses made up mostly of species of Andropogon, Boutelona, Bulbilis, Sorghastrum, Hordeum, and Aristida; (d) annual grasses, such as sorgos, sudan grass, millets, and cereals cut for hay; and (e) annual legumes, such as cowpeas, soybeans, peanuts, and mungbeans.

The discussion of this paper is confined to the fine forage-producing plants and for that reason such coarse forage-producing plants as corn and the sorghums were not included in the above classification.

## DISTRIBUTION OF GROUPS OF FORAGE PLANTS IN RELATION TO TYPES OF NATURAL VEGETATION

In a study of the ranges of adaptation and the climatic requirements of groups of cultivated crops it is well to take into account the types of natural vegetation encountered in their respective regions of distribution. Fig. 1 shows a generalized map of the natural vegetation regions of Oklahoma, taken from Shantz and Zon (2)[3]. Fig. 2 gives the rainfall map of the state, while Figs. 3, 4, 5, 6, and 7 show the distribution of the groups of forage crops listed above.

Five main types of natural vegetation are encountered in Oklahoma, *viz.*, (a) the tall grass or prairie grasslands, (b) the short grass

[3]Reference by number is to "Literature Cited," p. 223.

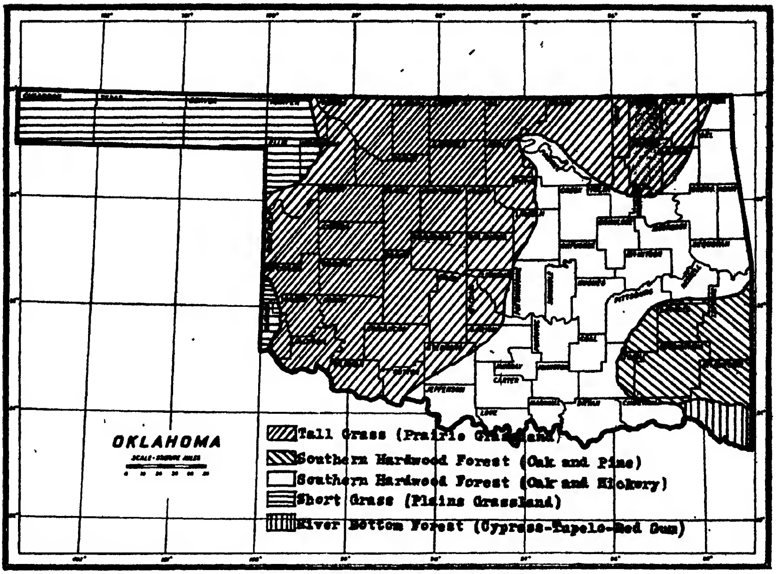


FIG. 1.—Generalized map of natural vegetation regions of Oklahoma. Taken from "The American Atlas of Agriculture" Section E (Natural Vegetation) by Shantz and Zon (2).

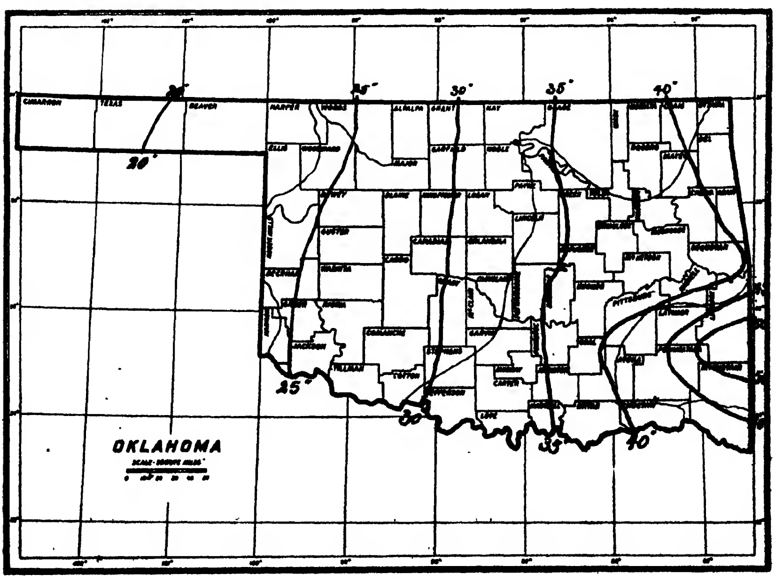


FIG. 2.—Rainfall map of Oklahoma, annual precipitation in inches.

or plains grasslands, (c) the southern hardwood forest (oak and pine), (d) the southern hardwood forest (oak and hickory), and (e) the river bottom forest (cypress-tupelo-red gum).

The tall grass region extends over the northern and west-central portions of the state. This is the predominating type on the upland soils around Stillwater and the type originally occurring on the plats devoted to the experimental work with grasses and legumes to be reported.

The short grass region is found in the extreme western and drier portions of the state. Climatic conditions in this section are too severe for the production of perennial cultivated grasses. In favorable locations alfalfa and sweet clover may be grown to a limited extent, otherwise most of the forage produced is from annual plants, primarily from the sorghums. The western expanse of the region designated in Fig. 1 as tall grass region constitutes in reality a transitional area between the tall grass and the short grass regions.

The southern hardwood forests extend over the eastern and south-east-central portions of the state; in the southeastern counties the oak and pine type predominates, farther north and west the oak and hickory type becomes of greater importance, while some of the river bottom forest is encountered along the Red River in the extreme southeastern corner of the state. The higher areas in the southern hardwood forest region (oak and hickory) have the tall grass or prairie type of vegetation, while on the other hand, the hardwood forests extend farther to the west along the principal rivers as edapic formations than is indicated in Fig. 1.

## (*a*) ALFALFA

Alfalfa production, as may be noticed from Figs. 1 and 3, reaches its highest development on the prairie grasslands and in the transitional region between the southern hardwood forest (oak and hickory) and the tall grass prairie. In the region of maximum production the annual rainfall is around 30 inches (Fig. 2). In this section the soils devoted to alfalfa production are deep and sufficiently porous for the rapid penetration and the subsequent storage of moisture. Alfalfa production decreases greatly as the short grass region is approached where not only the amount of precipitation decreases as the rate of evaporation increases, but where also the soil has a tendency to become less permeable. In the extreme western portions of the state alfalfa succeeds only on well-watered, permeable soils. These facts are in agreement with Weaver's (4, 5) observations.

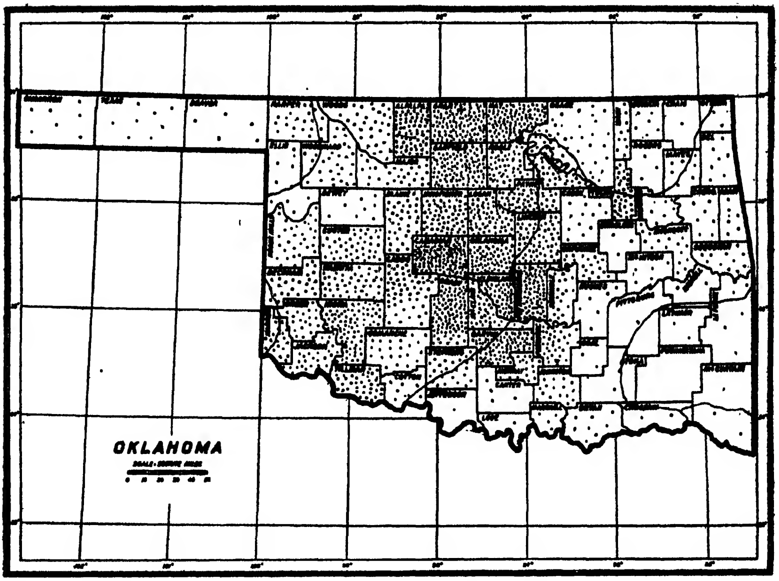


FIG. 3.—Alfalfa hay production in Oklahoma. One dot is equal to 100 acres. Taken from 1925 Census of Agriculture.

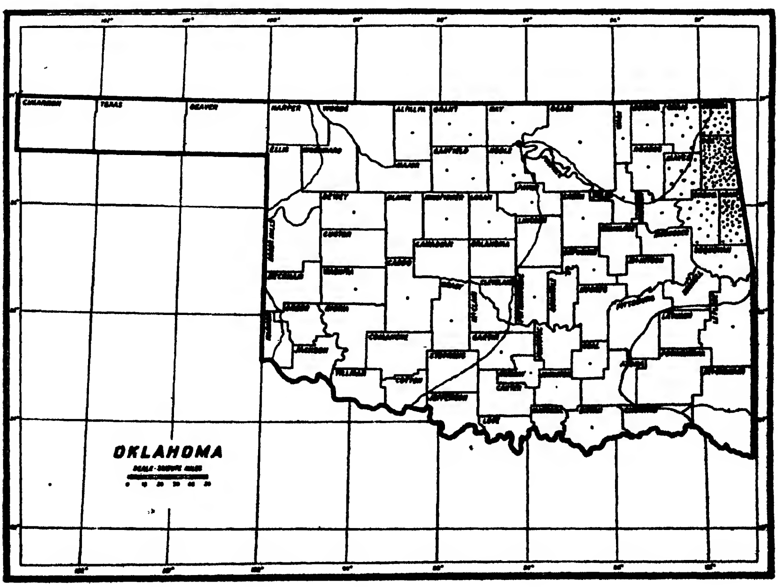


FIG. 4.—Cultivated perennial grasses and legumes. One dot is equal to 100 acres. Taken from 1925 Census of Agriculture.

### (*b*) CULTIVATED PERENNIAL GRASSES

The distribution of this group was taken from three separate headings as given in the census report, namely, "timothy alone," "timothy and red clover mixed," and "clover—red, alsike, and mammoth." The aggregate distribution of the crops under these three separate headings shows, as near as can be ascertained from the census report, the distribution of class (b) cultivated perennial grasses and legumes. It does not include, however, the distribution of such grasses as orchard grass and redtop, two grasses that are of importance in the northeastern portion of the state. In Oklahoma the grouping "other tame grasses cut for hay" as given in the census report is made up in the central and western parts of the state mainly of annual grasses, such as sudan grass, sorgos, millets, etc. In the extreme eastern, more particularly in the northeastern counties of the state, the grouping "other tame grasses cut for hay" includes such perennial grasses as orchard grass, redtop, meadow fescue, and Kentucky bluegrass. Allowance for this fact must be made in the interpretation of Fig. 6 on the distribution of annual grasses.

It will be noticed from Fig. 4 that the distribution of cultivated grasses and the true clovers cut for hay is limited almost entirely to three northeastern counties or to the northeastern portion of the southern hardwood (oak and hickory) forest where the summer temperature is moderate and the annual rainfall around 40 inches.

Bermuda falls naturally into the grouping of cultivated perennial grasses, yet the growth requirements of bermuda differ greatly from the grasses mentioned above. The distribution of perennial northern grasses in Oklahoma is limited mainly by high summer termperatures and lack of moisture. The distribution of bermuda, on the other hand, is not limited by high temperature as would be expected from its origin. Lack of moisture, however, does constitute a decided limiting factor to the distribution of this grass. Bermuda makes its most luxuriant growth in those sections of the state having a precipitation of around 40 inches annually. It grows quite well in sections with only 35 inches of rainfall but becomes of minor agricultural value as the 30-inch rainfall line is approached. In the extreme northern parts of the state low winter temperatures introduce a hazard to bermuda grass production.

### (*c*) NATIVE GRASSES

Prairie hay production in Oklahoma (Fig. 5) centers around the northeastern and north central portions of the state. The continuity of the prairie hay producing area of northeastern Oklahoma is broken

into by the extensive pasture lands of Osage County. Prairie hay production reaches its highest development in the eastern portion of the tall grass or prairie grasslands and on the transitional region between this area and the southern hardwood (oak and hickory) forests. Prairie hay production is of some importance in the oak and hickory region, of little importance in the oak and pine area, and of even less importance in the western portion of the tall grass prairie and in the transitional region between the prairie and plains grasslands. Luxuriant growth of native grasses cannot be attained where the annual rainfall drops much below 35 inches, except under very favorable soil conditions.

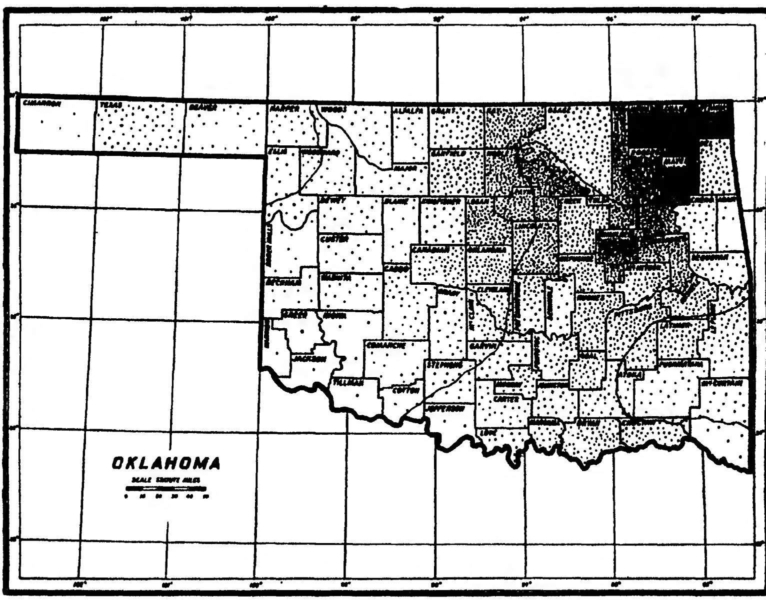


FIG. 5.—Prairie hay production in Oklahoma. One dot is equal to 100 acres. Taken from 1925 Census of Agriculture.

### (*d*) ANNUAL GRASSES

The acreage devoted to the production of annual grasses cut for hay is given in Fig. 6. The data for the construction of Fig. 6 were obtained by combining the respective acreages listed in the census report under the separate headings of "other tame grasses" and "small grains cut for hay." In the extreme western part of the state the group "other tame grasses" includes some perennial grasses, as has already been pointed out. Except in the extreme eastern counties

this class is made up mainly of annuals cut for hay, such as sorgos, sudan grass, and millets. Annual hays are grown quite generally over the state. The center of production is found in the central and south-central portion or in the transitional region between the southern hardwood (oak and hickory) forest and the tall grass regions in a sector where the annual rainfall averages from 30 to 35 inches.

The annual hay producing section is found farther west than the section producing hays from perennial grasses, farther west and south than the main prairie hay producing center, farther south than the alfalfa hay producing area, and extends farther into the plains grass-lands in the extreme western portions of the state than alfalfa.

It is well to notice that annual grasses do not assume a very important place as hay crops in those sections where alfalfa and prairie hays are produced extensively. Much of the acreage now devoted to the production of annual hays in the central part of the state is suited to alfalfa production, while on the other hand, many of the soils encountered in this section are either too shallow or lacking in permeability for the successful production of alfalfa.

### (*e*) ANNUAL LEGUMES

The acreage devoted to the production of annual legumes cut for hay (Fig. 7) is small. It is quite well distributed over the eastern and central portions of the state. The 30-inch rainfall line marks the western limit of production.

## EXPERIMENTAL WORK

### YIELDS OF GRASSES AND LEGUMES

Tables 1 and 2 give the 1927 and 1928 yields of grasses and legumes on plats planted in the spring and fall of 1926. Spring plantings were in the three years of the experiment accomplished early in March; fall plantings during the first part of September.

Some of the yields reported in Tables 1 and 2 are extremely high, due in part to the small size of plats used (1 square rod) and the consequent border effects, and in part due to the care and attention given the plats especially during the unfavorable season of 1926. A large percentage of the less vigorous grasses and legumes included in the test would not have survived the summer of 1926 but for close hand weeding. Table 3 gives the climatic conditions at Stillwater for the years 1926, 1927, and 1928. The months of March, April, and May of 1926 were exceptionally dry; furthermore the mean temperature of May was 2.5° F above normal. All grasses and legumes planted in the spring of 1926 were severely damaged by the dry and hot weather during the early part of the season but revived with the

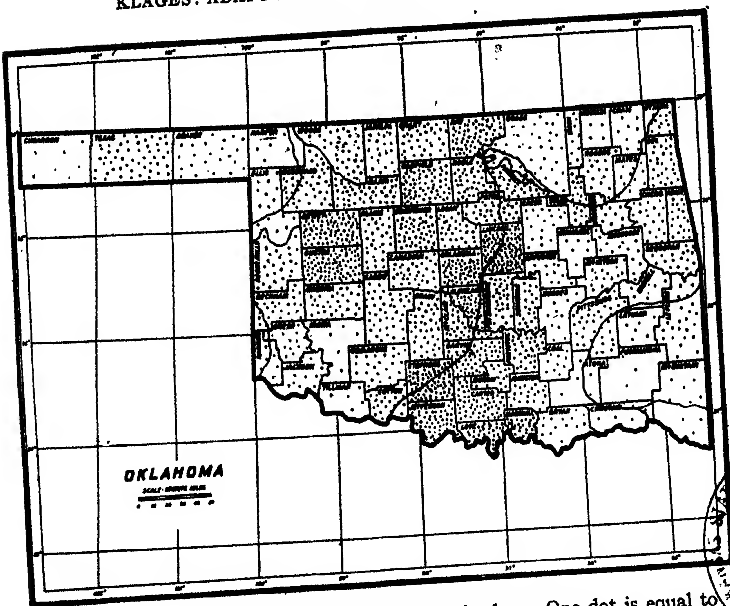


FIG. 6.—Annual grasses and small grains cut for hay. One dot is equal to 100 acres. Taken from 1925 Census of Agriculture.

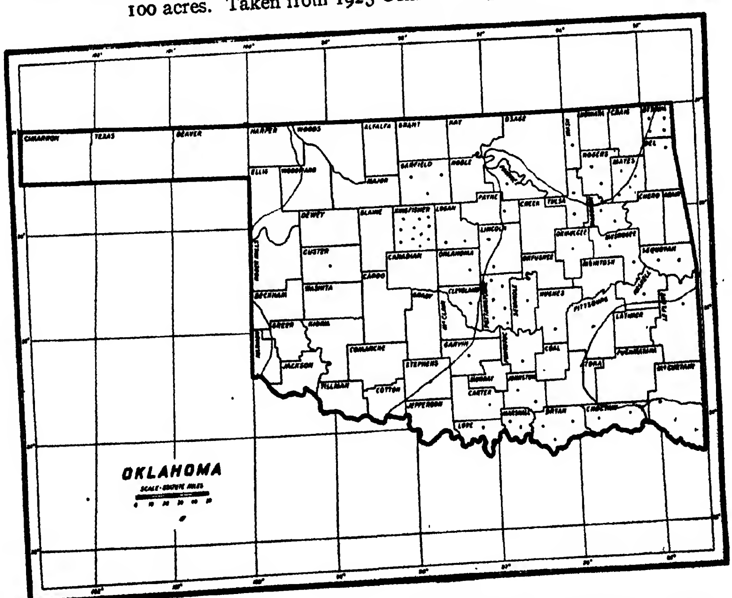


FIG. 7.—Annual legumes cut for hay. One dot is equal to 100 acres. Taken from the 1925 Census of Agriculture.

coming of rain in June; most of them, except those that will be pointed out later, survived the unfavorable conditions during July and August to be thoroughly revived by an abundance of rain in September. The season of 1927 was exceptionally favorable to the growth of grasses, the mean temperatures for the critical months of June, July, August, and September were below normal, while the rainfall for the months of June, August, and September was greatly in excess of the normal amounts. The early months of the season of 1928 were as favorable as those of 1927; after the middle of July considerable dry weather was encountered.

TABLE 1.—*Yields in 1927 in tons per acre of plats of grasses and legumes planted in 1926.*

| Crop | Time of seeding: March, First cut | March, Second cut | March, Total | March, Rank | September, First cut | September, Second cut | September, Total | September, Rank |
|---|---|---|---|---|---|---|---|---|
| | | Grasses | | | | | | |
| Tall oat, *Arrhenatherum elatius* | 3.36 | 1.80 | 5.16 | 1 | 2.08 | 0.72 | 2.80 | 3 |
| English rye, *Lolium perenne* | 3.52 | 1.26 | 4.78* | 2 | 4.32 | 0.80 | 5.12 | 1 |
| Orchard, *Dactylis glomerata* | 3.20 | 1.36 | 4.56 | 3 | 0.72 | 0.40 | 1.12 | 6 |
| Brome, *Bromus inermis* | 3.20 | 1.20 | 4.40 | 4 | 0.24 | — | 0.24 | 9 |
| Meadow fescue. *Festuca elatior* | 3.04 | 0.68 | 3.72 | 5 | 1.24 | 0.32 | 1.55 | 5 |
| Redtop, *Agrostis palustris* | 2.88 | 0.52 | 3.40 | 6 | 1.92 | 0.16 | 2.08 | 4 |
| Italian rye, *L. multiflorum* | 2.08 | 0.72 | 2.80† | 7 | 3.28 | 0.80 | 4.08 | 2 |
| Timothy, *Phleum pratense* | 2.08 | — | 2.08 | 8 | 0.40 | — | 0.40 | 8 |
| Bermuda, *Cynodon dactylon* | 0.96 | 1.04 | 2.00 | 9 | — Winterkilled | | | — |
| Sheep fescue, *F. ovina* | 1.36 | — | 1.36 | 10 | 0.20 | — | 0.20 | 10 |
| Hard fescue, *F. duriuscula* | 1.28 | — | 1.28 | 11 | 0.20 | — | 0.20 | 11 |
| Red fescue, *F. rubra* | 1.28 | — | 1.28 | 12 | 0.20 | — | 0.20 | 12 |
| Slender wheat, *Agropyron tenerum* | 1.28 | — | 1.28 | 13 | 1.04 | — | 1.04 | 7 |
| Kentucky blue, *Poa pratensis* | 0.80 | 0.24 | 1.04 | 14 | 0.20 | — | 0.20 | 13 |
| Dallis, *Paspalum dilatatum* | 0.40 | — | 0.40 | 15 | — Winterkilled | | | — |
| Creeping bent, *Agrostis stolonifera* | 0.24 | — | 0.24 | 16 | 0.12 | — | 0.12 | 14 |
| Carpet, *Axonopus compressus* | 0.12 | — | 0.12 | 17 | — Winterkilled | | | — |

TABLE 1.—*Continued.*

| Crop | March: First cut | March: Second cut | March: Total | March: Rank | September: First cut | September: Second cut | September: Total | September: Rank |
|---|---|---|---|---|---|---|---|---|
| **Legumes** | | | | | | | | |
| Red clover, *Trifolium pratense* | 2.96 | 2.56 | 5.52 | 1 | 0.64 | 0.40 | 1.04 | 3 |
| Alfalfa, *Medicago sativa* | Three crops | | 4.56 | 2 | 0.75 | 0.80 | 1.60 | 2 |
| Alsike clover, *T. hybridum* | 2.32 | 1.44 | 3.76 | 3 | 0.20 | — | 0.20 | 8 |
| Sweet clover, *Melilotus alba* | 3.36 | — | 3.36 | 4 | 0.16 | — | 0.16 | 9 |
| Sweet clover, *M. officinalis* | 2.48 | — | 2.48 | 5 | 0.96 | — | 0.96 | 4 |
| Black medic, *Medicago lupulina* | 2.08 | 0.12 | 2.20 | 6 | — | — | — | — |
| White clover, *T. repens* | 1.16 | 0.60 | 1.76 | 7 | 0.12 | 0.04 | 0.16 | 10 |
| Subterranean clover, *T. subterraneum*‡ | 1.76 | — | 1.76 | 8 | 0.24 | — | 0.24 | 7 |
| Korean Lespedeza, *Lespedeza stipulaceae*‡ | 1.65 | — | 1.65 | 9 | — | — | — | — |
| Japanese lespedeza, *L. striata* | 0.95 | — | 0.95 | 10 | — | — | — | — |
| Crimson clover, *T. incarnatum* | 0.30 | — | 0.30 | 11 | 1.76 | — | 1.76 | 1 |
| Bur clover, *Medicago arabica*‡ | 0.10 | — | 0.10 | 12 | 0.32 | — | 0.32 | 5 |
| Ladino clover, *T. repens latum* | — | — | — | — | 0.24 | 0.08 | 0.32 | 6 |
| Sweet clover, *M. alba annua* | — | — | — | — | 0.10 | — | 0.10 | 11 |

*Partly volunteer crop from seed produced in 1926.
†Mixture of *Lolium multiflorum* and *L. perenne*.
‡Planted March, 1927.

Table 4 gives the 1928 yields of plats planted in the spring of 1927. It will be noticed that the yields are much lower than those reported in Tables 1 and 2. This is due to the fact that the 1927 plats were located on a fairly weedy piece of land and that they did not have the benefit of a weeding as did the 1926 plats. As a result the finer grasses were thrown into direct competition with weedy growths.

### YIELD OF GRASSES DURING THE FIRST VEGETATIVE SEASON

Table 5 gives the yields of the grasses referred to in previous tables during their first vegetative season following spring seedings. Two series are given for 1928, the yields of series (a) were obtained from square rod plats located on fairly weedy land; those of series (b) from 1/29 acre plats located on clean land.

TABLE 2.—*Yields in 1928 in tons per acre of plats of grasses and legumes planted in 1926.*

| Crop | Time of seeding: March, First cut | March, Second cut | March, Total | March, Rank | September, First cut | September, Second cut | September, Total | September, Rank |
|---|---|---|---|---|---|---|---|---|
| | | | | Grasses | | | | |
| Tall oat, *Arrhenatherum elatius* | 2.16 | 1.10 | 3.16 | 1 | 1.60 | 0.82 | 2.42 | 2 |
| English rye, *Lolium perenne* | — | Dead | — | — | — | Dead | Dead | — |
| Orchard, *Dactylis glomerata* | 0.92 | 0.80 | 1.72 | 3 | 0.68 | 0.24 | 0.92 | 3 |
| Brome, *Bromus inermis* | 0.28 | 0.22 | 0.50 | 5 | 0.56 | 0.16 | 0.66 | 4 |
| Meadow fescue, *Festuca elatior* | 0.56 | 0.24 | 0.80 | 4 | 0.40 | 0.24 | 0.64 | 5 |
| Redtop, *Agrostis palustris* | 1.26 | 0.56 | 1.82 | 2 | 1.76 | 0.82 | 2.58 | 1 |
| Italian rye, *L. multiflorum* | — | Dead | — | — | — | Dead | — | — |
| Timothy, *Phleum pratense* | 0.32 | — | 0.32 | 10 | 0.24 | 0.04 | 0.28 | 7 |
| Bermuda, *Cynodon dactylon* | 0.08 | 0.22 | 0.30 | 11 | — | Dead | — | — |
| Sheep fescue, *F. ovina* | 0.32 | — | 0.32 | 7 | 0.28 | — | 0.28 | 8 |
| Hard fescue, *F. durisucula* | 0.32 | — | 0.32 | 8 | 0.28 | — | 0.28 | 9 |
| Red fescue, *F. rubra* | 0.32 | — | 0.32 | 9 | 0.28 | — | 0.28 | 10 |
| Slender wheat, *Agropyron tenerum* | 0.04 | — | 0.04 | 13 | 0.08 | — | 0.08 | 12 |
| Kentucky blue, *Poa pratensis* | 0.24 | 0.12 | 0.36 | 6 | 0.24 | 0.08 | 0.32 | 6 |
| Dallis, *Paspalum dilatatatum* | — | Dead | — | — | — | Dead | — | — |
| Creeping bent, *Agrostis stolonifera* | 0.16 | — | 0.16 | 12 | 0.12 | — | 0.12 | 11 |
| Carpet. *Axonopus compressus* | — | Dead | — | — | — | Dead | — | — |
| | | | | Legumes | | | | |
| Red clover, *Trifolium pratense* | 1.88 | 0.72 | 2.60 | 2 | 0.56 | 0.24 | 0.80 | 2 |
| Alfalfa, *Medicago sativa* | Three crops | | 4.02 | 1 | Three crops | | 2.70 | 1 |
| Alsike clover, *T. hybridum* | 1.08 | 0.56 | 1.64 | 3 | 0.40 | 0.16 | 0.56 | 3 |
| Sweet clover, *Melilotus alba* | — | Dead | — | — | — | Dead | — | — |
| Sweet clover, *M. officinalis* | — | Dead | — | — | — | Dead | — | — |
| Black medic, *Medicago lupulina* | 0.16 | 0.04 | 0.20 | 5 | — | — | — | — |
| White clover, *T. repens* | 0.24 | 0.12 | 0.36 | 4 | 0.20 | 0.08 | 0.28 | 5 |
| Ladino clover, *T. repens latum* | — | — | — | — | 0.24 | 0.08 | 0.32 | 4 |

TABLE 3.—*Climatic conditions at Stillwater, Oklahoma, for the years 1926, 1927, and 1928.*

| | Mean temperature, °F | Departure from normal, °F | Highest temperature, °F | Lowest temperature, °F | Precipitation, inches | Departure from normal, inches |
|---|---|---|---|---|---|---|
| | | | 1926 | | | |
| January | 35.5 | —1.6 | 62 | 8 | 1.78 | +0.72 |
| February | 43.0 | +5.6 | 76 | 21 | 0.05 | —1.25 |
| March | 44.4 | —6.3 | 77 | 19 | 1.23 | —1.07 |
| April | 54.9 | —4.3 | 84 | 27 | 1.73 | —2.03 |
| May | 69.7 | +2.5 | 95 | 38 | 2.63 | —2.59 |
| June | 75.9 | +0.1 | 95 | 53 | 4.74 | +0.96 |
| July | 78.9 | —1.0 | 101 | 55 | 3.04 | —0.16 |
| August | 80.6 | +0.1 | 103 | 54 | 1.44 | —1.99 |
| September | 71.8 | —1.3 | 95 | 42 | 7.07 | +3.66 |
| October | 64.6 | +3.7 | 89 | 35 | 4.41 | +1.39 |
| November | 46.3 | —2.4 | 76 | 19 | 1.76 | —0.39 |
| December | 40.6 | +1.8 | 73 | 6 | 2.84 | +1.40 |
| | | | 1927 | | | |
| January | 37.9 | +0.8 | 72 | 5 | 1.16 | +0.09 |
| February | 47.3 | +9.9 | 77 | 11 | 0.68 | —0.62 |
| March | 49.6 | —1.1 | 79 | 19 | 1.74 | —0.56 |
| April | 64.0 | +4.8 | 89 | 33 | 4.30 | +0.54 |
| May | 71.0 | +3.8 | 94 | 42 | 2.26 | —2.96 |
| June | 75.6 | —0.2 | 96 | 57 | 7.46 | +3.68 |
| July | 79.4 | —0.4 | 98 | 58 | 2.33 | —0.55 |
| August | 76.1 | —4.4 | 96 | 55 | 4.41 | +0.98 |
| September | 73.0 | —0.1 | 94 | 38 | 6.57 | +3.16 |
| October | 65.0 | +4.1 | 89 | 39 | 2.72 | —0.30 |
| November | 53.7 | +5.0 | 80 | 25 | 2.84 | +0.69 |
| December | 35.4 | —3.4 | 66 | —1 | 1.63 | +0.19 |
| | | | 1928 | | | |
| January | 40.0 | +3.3 | 14 | 0 | 0.30 | —0.78 |
| February | 43.6 | +4.8 | 70 | 15 | 1.38 | +0.17 |
| March | 53.3 | +3.5 | 86 | 26 | 3.07 | +0.68 |
| April | 57.8 | —1.3 | 85 | 23 | 4.44 | +0.44 |
| May | 70.0 | +2.5 | 98 | 42 | 3.27 | —1.79 |
| June | 74.0 | —2.6 | 95 | 51 | 6.11 | +2.26 |
| July | 80.6 | +0.1 | 97 | 64 | 1.90 | —0.95 |
| August | 81.3 | +0.6 | 100 | 61 | 2.02 | —1.05 |
| September | 71.6 | —1.5 | 94 | 45 | 0.37 | —3.40 |
| October | 66.0 | +5.4 | 94 | 39 | 3.33 | +0.39 |
| November | — | — | — | — | — | — |
| December | — | — | — | — | — | — |

It will be of interest to compare the relative performances of the several grasses during the first vegetative season with a classification given by Sinz (3) as a result of pot experiments in Germany in so far as the grasses are represented in the two separate investigations. Sinz

TABLE 4.—*Yields in 1928 of plats of grasses and legumes planted in the spring of 1927.*

| Crop | Yield in tons per acre |
|---|---|
| Grasses | |
| Tall oat, *Arrhenatherum elatius* | 0.96 |
| Orchard, *Dactylis glomerata* | 0.88 |
| Meadow fescue, *Festuca elatior* | 0.64 |
| Redtop, *Agrostis palustris* | 0.60 |
| Timothy, *Phleum pratense* | 0.24 |
| Brome, *Bromus enermis* | 0.12 |
| Kentucky blue, *Poa pratensis* | 0.08 |
| Canada blue, *P. compressa* | 0.06 |
| Sheep fescue, *F. ovina* | 0.04 |
| Creeping bent, *A. stolonifera* | Dead |
| English rye, *Lolium perenne* | Dead |
| Italian rye, *L. multiflorum* | Dead |
| Dallis, *Paspalum dilatatum* | Dead |
| Carpet, *Axonopus compresssus* | Dead |
| Legumes | |
| Sweet clover, *Melilotus alba* | 2.40 |
| Sweet clover, *M. officinalis* | 2.40 |
| Red clover, *Trifolium pratense* | 1.60 |
| Alsike clover, *T. hybridum* | 0.32 |
| Alfalfa, *Medicago sativa* | 0.32 |
| Black medic, *Medicago lupulina* | 0.16 |
| White clover, *T. repens* | 0.04 |

TABLE 5.—*Relative performance of grasses during their first vegetative season following spring seedings, yields in tone per acre.*

| Grasses | Year 1926 | 1927 | 1928 Series (a) | 1928 Series (b) | Average |
|---|---|---|---|---|---|
| Group A (Rapid Development) | | | | | |
| Dallis, *Paspalum dilatatum* | 1.60 | 1.25 | — | — | 1.43 |
| English rye, *Lolium perenne* | 0.76 | 0.48 | 1.19 | 0.96 | 0.85 |
| Italian rye, *L. multiflorum* | 0.72 | 0.48 | — | 1.04 | 0.75 |
| Tall oat, *Arrhenatherum elatius* | 0.72 | 0.84 | 0.78* | 0.56 | 0.73 |
| Group B (Medium Development) | | | | | |
| Orchard, *Dactylis glomerata* | 0.36 | 0.32 | 1.01 | 0.32 | 0.50 |
| Meadow fescue, *Festuca elatior* | 0.32 | 0.32 | 0.77 | 0.24 | 0.41 |
| Bermuda, *Cynodon dactylon* | 0.32 | 0.40 | — | — | 0.36 |
| Brome, *Bromus inermis* | 0.28 | 0.08 | 0.68 | 0.32 | 0.34 |
| Redtop, *Agrostis palustris* | 0.24 | 0.24 | 0.42 | 0.24 | 0.29 |
| Group C (Slow Development) | | | | | |
| Slender wheat, *Agropyron tenerum* | 0.24 | 0.06 | — | 0.28 | 0.19 |
| Kentucky blue, *Poa pratensis* | 0.12 | — | — | — | 0.12 |
| Carpet, *Axonopus compressus* | 0.08 | 0.12 | — | — | 0.10 |
| Timothy, *Phleum pratense* | 0.06 | 0.06 | — | — | 0.06 |
| Creeping Bent, *Agrostis stolonifera* | 0.08 | 0.04 | — | — | 0.06 |
| Sheep fescue, *F. ovina* | 0.08 | 0.04 | — | 0.04 | 0.05 |

*75% of a full stand.

grew his plants in containers holding 19 kg of soil, the moisture content of which was kept constant at 70% of its water-holding capacity. The plants not being subjected to drought nor to the at times high temperatures of an Oklahoma summer were grown under more favorable conditions than those reported on in Table 5. Sinz classified the grasses used in his investigation on the basis of weights of tops and roots into four classes in order of their relative rates of development. His classification, together with the relative yields of the separate grasses on a percentage basis of the yield of English rye grass, is given in Table 6. The grasses were planted on April 15 and harvested on June 17.

TABLE 6.—*Classification of grasses relative to their rates of development during the first vegetative season, with weights of tops and roots expressed on a percentage basis of those of Lolium perenne.**

| Grasses | Weights of tops | Weights of roots | Proportion of tops to roots |
|---|---|---|---|
| Group A (Rapid Development) | | | |
| English rye, *Lolium perenne* | 100.0 | 100.0 | 1.76 |
| Meadow fescue, *Festuca elatior* | 109.0 | 125.2 | 1.54 |
| Italian rye, *L. italicum* | 105.2 | 95.8 | 1.93 |
| Tall oat, *Avena elatior* | 79.2 | 51.0 | 2.71 |
| Group B (Medium Development) | | | |
| Timothy, *Phleum pratense* | 63.2 | 39.3 | 2.81 |
| Orchard, *Dactylis glomerata* | 59.6 | 46.5 | 2.24 |
| Meadow foxtail, *Alopecurus pratensis* | 58.0 | 53.8 | 1.93 |
| Group C (Slow Development) | | | |
| Rough stalked meadow, *Poa trivialis* | 67.9 | 30.0 | 3.96 |
| Creeping bent, *Agrostis stolonifera* | 65.9 | 35.9 | 3.20 |
| Crested dogstail, *Cynosurus cristatus* | 55.5 | 38.2 | 2.55 |
| Group D (Very Slow Development) | | | |
| Sheep fescue, *Festuca ovina* | 28.9 | 27.6 | 1.83 |
| Kentucky blue, *Poa pratensis* | 27.4 | 18.6 | 2.51 |

*Compiled from Sinz.

It is well to note that many of the grasses included in both Tables 5 and 6 assume much the same relative positions in the two tables. There are, however, some notable exceptions as would be expected under the different climatic conditions, notably the position of timothy and meadow fescue. Timothy especially makes a slow growth under Oklahoma conditions, while meadow fescue is slower to establish itself than either tall oat or orchard grass. The rye grasses stand out for their rapid habits of growth in both lists.

## RANGES OF ADAPTATION OF INDIVIDUAL SPECIES OF GRASSES

1. *Tall oat grass (Arrhenatherum elatius)*.—Tall oat has shown itself to be well adapted to survival under droughty and high temperature

conditions. The plants are long lived, so far having survived three summers without any material reduction in stand. It became evident that a larger crop may be expected from tall oat than from orchard grass during the first season especially following fall seedings. The earliness of this grass has much to do with its ability to withstand drought and in part accounts for its good recovery after the removal of the first crop. It languished during the hottest part of summer but recovered quickly with the advent of fall rains and lower temperatures. The yields of this grass as may be seen from foregoing tables were uniformly high. Good stands were obtained with the employment of 30 pounds of seed per acre. One of the main factors limiting the employment of tall oat grass is the high cost of seeding.

2. *The rye grasses* (*Lolium perenne* and *L. multiflorum*).—English rye grass (*L. perenne*) is recognized as a perennial, while Italian rye grass (*L. multiflorum*) is generally regarded as an annual. Under Oklahoma conditions both of these grasses showed a tendency to behave as annuals. The plat of English rye grass sown in the spring of 1926 produced a yield of 0.76 ton per acre during that season (Table 5). The plants were sufficiently ripe to have viable seed at the time of harvest. After the crop was removed in July, 75% of the plants succumbed. The remaining plants revived with the coming of rains in September. These plants, together with those coming from the volunteer seed, produced a good stand and gave the high yield of 4.78 tons per acre in two crops in 1927 as reported in Table 1. The plat of Italian rye grass planted in the spring of 1926 contained a considerable admixture of *L. perenne*. This plat was cut at the same stage as the plat of English rye grass referred to above, consequently its yield in 1927 was produced mainly by surviving plants of *L. perenne* and volunteer plants of both *L. perenne* and *L. multiflorum*. In 1927 all rye grass plats were cut at the proper stage for hay production with the result that all plants died after the removal of the second crop. This was the case with both the *L. perenne* and the *L. multiflorum* and with the plats sown in the spring as well as with those sown in the fall of 1926. The plants of the 1927-sown plats died after the removal of the crop as did also those sown in the spring of 1928.

The rye grasses stand out for their rapidity of growth. Due to their earliness they make practically all their growth during the cool portions of the year. They have shown themselves to be unable to withstand high temperatures. The failure of English rye grass to survive a favorable season such as 1927 shows that this grass has only a limited range of usefulness in north-central Oklahoma. The high yields of that season (Table 1), as well as the high yields of the spring-

sown plats of 1928 (Table 5), were attained during the relatively cool and moist spring and early summer months, the plants being unable to survive the higher temperatures of the later months.

3. *Orchard grass (Dactylis glomerata)*.—Orchard grass showed a high degree of drought resistance as well as ability to recover quickly after its growth had been cut down by dry hot weather. After it had once established itself its yields compared well with those of tall oat grass. Orchard grass was slower than tall oat grass to establish itself, nor did it prove to be as long lived. Stands on plats surviving three summers show an appreciable reduction.

4. *Smooth brome (Bromus inermis)*.—Smooth brome gave a high yield in 1927 on the plat planted in the spring of 1926 (Table 1). In other years the yields were low. This grass is known for its drought resistance. The temperatures encountered during an average Oklahoma summer proved too high for this grass. The vitality of the brome grass was reduced to the extent that it was unable to cope with weeds or to maintain itself. It is interesting to note that this grass, as well as some other typical northern sod-forming grasses to be pointed out later, showed a decided tendency towards a bunch habit of growth under Oklahoma conditions. Such conditions may result from a lack of vigor of these grasses under the particular set of climatic factors encountered in central Oklahoma.

5. *Meadow fescue (Festuca elatior)*.—Meadow fescue showed a fair degree of drought resistance. It does not make as vigorous a growth early in the season as tall oat or orchard grass. Meadow fescue has given fair yields, but has shown itself to lack in aggressiveness and is consequently poorly adapted to cope with weedy growths.

6. *Fine-leaved fescues (F. ovina, F. duriuscula, F. rubra)*.—These fine-leaved grasses, while producing but low yields, have shown themselves to be very drought resistant and long lived under Oklahoma conditions. There were no apparent differences in the general growing habits, general characteristics, and yielding abilities of these grasses. These fescues showed a densely tufted habit of growth with the culms attaining a height of 16 inches. They are extremely early, flowering towards the end of March. These grasses enter into a semi-dormant stage during the period of highest temperatures in summer but recover quickly with the advent of rain and lower temperatures.

7. *Redtop (Agrostis palustris)*.—Redtop has shown itself to be a dependable grass as may be seen from its uniformly high yield. It showed a remarkable resistance to drought and to high temperatures. Redtop proved to be aggressive and gave evidence of being long lived.

It recovered quickly after periods unfavorable to its growth. The outstanding fact about redtop was that it produced a better sod under Oklahoma conditions than any other northern grass which showed that its vitality was not impaired by the climatic conditions encountered.

8. *Creeping bent* (*Agrostis stolonifera*).—Creeping bent made only an inferior growth. Dry periods during the summer reduced the stand materially. It was unable to produce a sod even in a season as favorable as that of 1927. Stands improved during the cooler and moister portions of the year but summer temperatures were too severe for its survival.

9. *Timothy* (*Phleum pratense*).—Timothy has no place even in the most favorable locations in north-central Oklahoma. The high summer temperatures constitute the main limiting factor to its growth.

10. *Bermuda* (*Cynodon dactylon*).—The factors favoring and limiting the distribution and employment of bermuda have already been referred to. Bermuda is outstanding for its ability to grow under high temperature conditions and is fairly drought resistant. Even in the face of such disadvantages as susceptibility to low temperatures causing it to turn brown early in the fall and its late date of starting growth in the spring its high standing as a lawn grass has not been impaired by any other grass. A great problem arising in the employment of pure stands of bermuda is apparent from the 1927 and 1928 yields of the plat sown in the spring of 1926 (Tables 1 and 2). The 1927 yield was 2.00 tons as compared to only 0.30 ton per acre in 1928. This reduction in yield was due to the sod bound condition of the plat in 1928, three years after its establishment. Good stands of bermuda were obtained by the employment of 10 pounds of seed per acre.

11. *Slender wheat* (*Agropyron tenerum*).—Slender wheat grass has been a practical failure. It made good growths following seedings, developed rapidly during the cool portions of the season, only to languish or die with the advent of higher temperatures in May or June.

12. *Kentucky bluegrass* (*Poa pratensis*).—The occurrence of high temperatures and drought make this grass of questionable value in central Oklahoma. Stands of Kentucky bluegrass can be established with diligent care and attention. The grass lacks the aggressiveness of bermuda or redtop and is for that reason poorly adapted to cope with weedy growths. The fact that Kentucky bluegrass was unable to produce a sod but showed a decided bunch habit of growth brought out that its vitality was greatly reduced by the climatic conditions prevailing in central Oklahoma.

13. *Canada bluegrass* (*P. compressa*).—Considerable difficulty was encountered in obtaining viable seed of this grass. A plat with a full stand was established in the fall of 1925. A fair sod was produced in 1926, but the yields, as in subsequent years, were negligible. The grass was unable to compete with weeds and annual weedy grasses.

14. *Dallis grass* (*Paspalum dilatatum*).—Dallis grass was outstanding for its drought resistance and its ability to grow uninterruptedly under high temperature conditions. Its yields during the first seasons were high (Table 5). While summer conditions favored the growth of Dallis grass, it was unable to cope with winter temperatures in north-central Oklahoma. Practically the entire 1926 stand was killed out during the comparatively mild winter of 1926–27, while the entire stand of the 1927 plat was lost during the more severe winter of 1927–28.

15. *Carpet grass* (*Axonopus compressus*).—Carpet grass was extremely slow to establish itself, but few plants survived the dry summer months of 1926 only to be killed during the winter. Carpet grass was unable to cope with summer droughts and with winter temperatures.

RANGES OF ADAPTATION OF INDIVIDUAL SPECIES OF LEGUMES

1. *Alfalfa* (*Medicago sativa*).—Conditions limiting the growth of alfalfa have already been discussed. In these experiments the yields of alfalfa were outstanding, being surpassed only by those of sweet clover and red clover in certain instances.

2. *Red clover* (*Trifolium pratense*).—Some of the yields of red clover obtained in the course of this investigation were extremely high. What has previously been said concerning the attention given the plats of 1926 must be kept in mind in the interpretation of the high yields obtained in 1927. The season of 1927, as may be seen from Table 3, was exceptionally favorable to the growth of red clover as was also the early part of the season of 1928; yet the 1928 yields of the plat established in 1927 (Table 4) were considerably lower than the 1927 yields of the plat established in the previous year, reflecting the care given the plats in 1926. It is well to note the differences in the 1928 yields of red clover and alfalfa on the plats established in 1927. Red clover yielded 1.60 tons as compared to only 0.32 ton per acre for alfalfa. The difference was due mainly to the better stand of the red clover, showing that it is better able to cope with weedy growths than alfalfa in favorable seasons. It is an established fact that alfalfa is more drought resistant than red clover.

Due to the more or less artificial conditions under which the crop was established and to the favorable seasons encountered, the high

yields of red clover reported in this paper cannot be used as a basis of recommendation of this crop for central Oklahoma conditions.

3. *Alsike clover* (*T. hybridum*).—A wider range of climatic adaptation is generally ascribed to alsike than to red clover, Piper (1). The yields reported in this investigation do not on first consideration seem to bear out this contention. It should be kept in mind, however, that the climatic conditions in 1927 as well as in 1928 were favorable to the growth of both of these clovers. Under identical and favorable soil and climatic conditions red clover may naturally be expected to produce the higher yields. During the dry summer of 1926 it became evident that alsike clover was not as easily damaged by drought as red clover.

4. *White clover* (*T. repens*).—Good stands of white clover were obtained when it was sown on clean land. It is poorly adapted to compete with weeds. White clover made little growth during the middle of the summer but recovered quickly with the coming of rains and milder temperatures in the fall. Ladino clover (*T. repens latum*) showed practically the same growing habits as white clover

5. *Subterranean clover* (*T. subterraneum*).—This annual clover gave a fair yield in only one season and that with the aid of close hand weeding. It lacks in aggressiveness and in drought resistance to be of value for central Oklahoma.

6. *Crimson clover* (*T. incarnatum*).—Crimson clover produced a good yield on a plat sown in the fall of 1926. Spring seedings resulted in failure. Crimson clover seems sufficiently hardy to withstand winter conditions in central Oklahoma.

7. *Sweet clovers* (*Melilotus alba, M. officinalis, M. alba annua*).—The yields of sweet clover due to the coarseness of the material can hardly be compared with those of the finer-stemmed leguminous plants. White biennial sweet clover (*M. alba*) has given the better returns following spring seedings, while the yellow biennial sweet clover (*M. officinalis*), due to its greater degree of winterhardiness, has given best results following fall seedings. Annual sweet clover (*M. alba annua*) did not prove sufficiently hardy for fall seeding and was greatly surpassed in yield by the biennial types in the case of spring seeding.

8. *Black medic* (*Medicago lupulina*).—Black medic gave good yields in 1927 on a plat sown in 1926. It proved to be short lived. It was not as aggressive as white clover. Stands could be established only on clean land.

9. *Bur clover* (*Medicago arabica*).—Spotted bur clover did not prove sufficiently hardy to withstand winter conditions in north-

central Oklahoma, except in a few protected places. Spring plantings resulted in failure.

10. *Lespedeza* (*Lespedeza striata* and *L. stipulaceae*).—While showing some fairly good yields, lespedeza lacked in vigor and was severely damaged by dry weather. Fair yields were obtained on clean land, though the plants lacked in aggressiveness to compete against weedy growths. Korean (*L. stipulaceae*) as also Kobe (*L.* spp.) proved superior to Japanese lespedeza (*L. striata*). The Korean lespedeza was able to make more growth in early spring while fairly low temperatures still prevailed than the Japanese lespedeza. This characteristic enabled the Korean lespedeza to become thoroughly established sooner and to withstand drought somewhat better than the slower-developing Japanese lespedeza. In the dry summer of 1926 Korean lespedeza gave a yield of 1.25 tons as compared with 0.48 ton per acre for the Japanese. Under conditions prevailing in central Oklahoma Korean lespedeza was able to produce a good seed crop, while the Japanese lespedeza produces seed only sparingly.

## SUMMARY

The difficulties encountered in the selection of perennial forage plants in the southern Great Plains area are pointed out.

The distribution of groups of forage crops in relation to the types of native vegetation of Oklahoma is given, together with a discussion of the factors favoring and limiting the distribution of the several groups.

The yields, ranges of adaptation, factors favoring, and factors limiting the growth and employment of 18 species of cultivated grasses and 14 species of legumes are discussed.

Many of the northern grasses, such as timothy, creeping bent, Kentucky and Canada bluegrasses, smooth brome, and slender wheat, showed themselves to be poorly adapted to the high temperatures and the at times dry periods of the summers of central Oklahoma.

Such typical sod-forming grasses as creeping bent, Kentucky bluegrass, and smooth brome developed typical bunch habits of growth under prevailing conditions. This was taken as an index of lack of vigor and aggressiveness.

Meadow fescue, while more drought resistant and better able to endure high temperatures than the above-mentioned northern grasses, was not sufficiently vigorous to be of great value.

The fine-leaved fecsues, such as sheep, hard, and red fescue, while low yielders, have shown themselves to be very drought resistant or rather drought escaping due to their ability to grow early in the season.

The rye grasses, while producing high yields during the first vegetative season, especially following fall seedings, were short lived, behaving in practically all instances as annuals due to their inability to endure high summer temperatures.

Tall oat, orchard grass, and redtop showed themselves to be constant yielders with a high degree of drought and high temperature endurance and sufficiently aggressive to be of value on the better soils of east-central and eastern Oklahoma. They are not sufficiently drought resistant, however, for employment on thin, dry upland soils in the central part of the state. On the better, fairly well watered soils these grasses may well be grown in combination with sweet clover in the central and with alsike and red clover in the eastern part of the state.

Of the true southern grasses, bermuda alone proved sufficiently hardy to endure winter conditions in north-central Oklahoma. Carpet grass was not as drought resistant as bermuda. Dallis grass showed a most remarkable degree of drought resistance but was not winterhardy.

Alfalfa and sweet clover have shown themselves to be the most dependable legumes for central Oklahoma. None of the true clovers are in position to compete with these two crops in the central part of the state. As the more humid eastern part, especially the northeastern portion of the state, is approached a definite place is found for the true clovers. The true clovers can be grown in north-central Oklahoma only with special care and on well-watered soils.

Black medic and subterranean clover did not prove sufficiently drought resistant for Oklahoma conditions.

Bur clover was not sufficiently winterhardy for north-central Oklahoma, but it has a place in the eastern and southeastern portions of the state.

Crimson clover survived the winter of 1926–27 but did not yield enough to be of practical value.

The lespedezas lack in drought resistance to be of practical value in the central part of Oklahoma, except in special locations and for special purposes. They have a definite place in the more humid portions of the state. Both Korean and Kobe have shown themselves to be superior to Japanese lespedeza.

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# THE EFFECT OF ALFALFA ON SOIL MOISTURE[1]

F. L. DULEY[2]

In the sub-humid section of the United States reseeding old alfalfa fields immediately to the same crop often results in failure. Some have thought that these failures were due primarily to a depletion of the soil moisture by the previous alfalfa crop, and that if the land be used for other crops for a few years enough moisture will be accumulated to support again a normal growth of alfalfa. Studies relating to this question are being conducted at the Kansas Experiment Station, and it seems desirable to present at this time a preliminary report covering the results of three seasons' work.

## EXPERIMENTAL METHODS

The studies reported here were pursued as a part of the rotation and fertility experiments that have been in progress since 1910 on the agronomy farm of the Kansas Agricultural College. The soil is gently rolling upland. One series of plats (Series X) has been in alfalfa continuously since 1910, except that it was reseeded in 1923 and again in 1928. Plats 2, 11, and 12 of this series have been used for moisture determinations. These particular plats were chosen because they are located at slightly different elevations on the slope, but since the moisture contents proved to be very similar average results only are presented. Plats 2 and 11 have received no soil treatment, but plat 12 has had applications of manure and lime.

Four other plats (plat 1 of series I, II, III, and IV) which are in a 16-year rotation including alfalfa, corn, and wheat two years have also been used. In this rotation the plats are in alfalfa four years after which there is grown one crop of corn and two of wheat successively for a period of 12 years, and then reseeded to alfalfa. Series I was in alfalfa from 1922 to 1925, inclusive; series II from 1910 to 1913 and from 1926 to 1928; series III from 1918 to 1921; and series IV from 1914 to 1917. These plats have had annual applications of superphosphate. All of the rotation plats used in this study are near together, being separated only by a cross roadway. Also they are in the same field as are those continuously in alfalfa, but separated by about 600 feet and are at a slightly greater elevation.

Samples of soil for moisture determinations were taken in foot sections with a soil sampling tube to a depth of 10 feet. Duplicate samples were taken from each plat. The sampling was begun on the

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continuous alfalfa plats September 11, 1926, after a very severe drought. A second sampling was made in November 1926, and at this time the first samples were drawn from the rotation plats. Subsequent samplings from all plats were made in November 1927, May 1928, and August 1928. During this period the total rainfall was 72.59 inches, or approximately 16% above normal. From November 1927 to June 1928 it was slightly below normal, but during July 1928 it was 7.38 inches, or about 60% above normal.

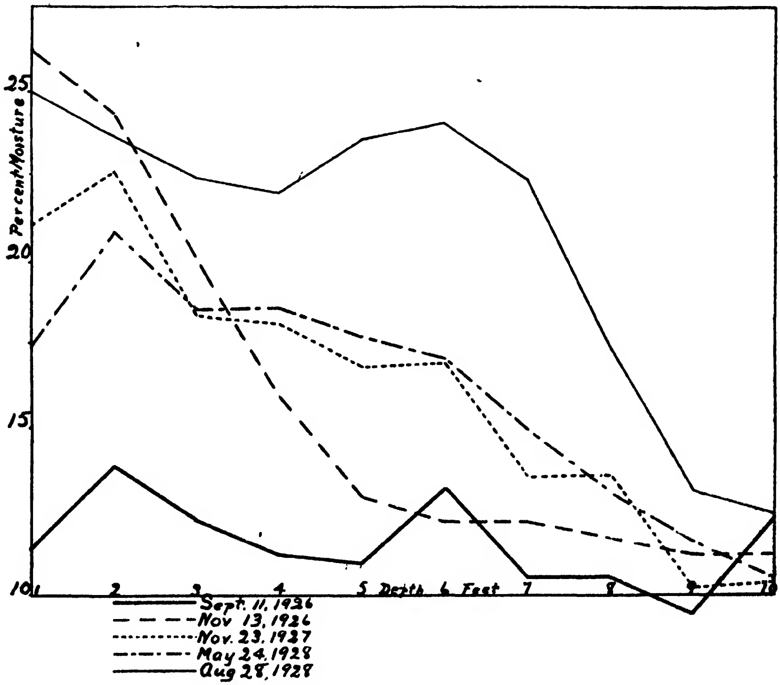


FIG. 1.—Average soil moisture content of plats continuously in alfalfa.

## RESULTS

The average moisture content of the soil at different depths for the three plats in continuous alfalfa is shown in Table 1 and Fig. 1. At the first four samplings, while the land was in alfalfa, there was a marked variation in the soil moisture down to a depth of about 6 feet. Below this depth the variation was between rather narrow limits. In other words, there was no great accumulation of water in the lower subsoil as long as the land remained in alfalfa.

From September 11, 1926, the date of the first sampling, until November 13, 1926, the date of the second sampling, the precipita-

TABLE 1.—*Average percentage of moisture of plats in continuous alfalfa, September 11, 1926, to August 28, 1928.*

| Depth in feet | Sept. 11, 1926 | Nov. 13, 1926 | Nov. 23, 1927 | May 24, 1928 | Aug. 28, 1928 |
|---|---|---|---|---|---|
| 1 | 11.4 | 26.2 | 21.0 | 17.4 | 25.0 |
| 2 | 13.8 | 24.3 | 22.6 | 21.8 | 23.7 |
| 3 | 12.2 | 20.0 | 18.3 | 18.5 | 22.4 |
| 4 | 11.2 | 15.9 | 18.1 | 18.6 | 22.0 |
| 5 | 10.9 | 12.9 | 16.8 | 17.7 | 23.6 |
| 6 | 13.2 | 12.2 | 16.9 | 17.1 | 24.1 |
| 7 | 10.5 | 12.2 | 13.5 | 14.9 | 22.4 |
| 8 | 10.5 | 11.7 | 13.6 | 13.1 | 17.4 |
| 9 | 9.4 | 11.2 | 10.2 | 11.6 | 13.1 |
| 10 | 12.2 | 11.2 | 10.3 | 10.5 | 12.4 |
| Average 10 feet | 11.5 | 15.8 | 16.1 | 16.1 | 20.6 |
| Average 0–5 feet | 11.9 | 19.9 | 19.4 | 18.8 | 23.3 |
| Average 6–10 feet | 11.2 | 11.7 | 12.9 | 13.4 | 17.9 |

tion was 12.02 inches. A fair crop of alfalfa hay was produced during this time. The average moisture content to a depth of 10 feet increased from 11.5% to 15.8%, but the increase was practically all in the upper 5 feet, the average increase here being 8%. In the lower 5 feet the increase was only 0.5%. This shows that during this time very little of the water penetrated below a depth of 5 feet.

During the next year, i.e., from November 13, 1926, to November 23, 1927, there was a total precipitation of 37.85 inches which is 6.42 inches above normal. The average increase in moisture to a depth of 10 feet was only 0.3%. There was, however, a slight increase in the subsoil moisture, the average increase of the sixth to tenth foot section being 1.2%. This was possibly due to the fact that the stand of alfalfa was partly killed out in 1927. The average moisture content on May 24, 1928, was exactly the same as in November 1927, but the distribution had slightly changed in that there had been a decrease in the upper layers and an increase in the lower, indicating a gradual downward movement of moisture during the winter. The rainfall during this period was 6.62 inches.

This land was plowed June 6, 1928, and fallowed until August in preparation for seeding. The results show that there was a marked accumulation of soil moisture during this period. The average increase to a depth of 10 feet was 4.5%. Fig. 1 shows that this increase was somewhat irregular but extended to the full depth of 10 feet. The precipitation from May 24 to August 28 was 16.10 inches, and since the land carried no crop conditions were favorable for moisture penetration to the lower subsoil.

The results from the rotation plats also show very slight variation in the moisture content of the soil below 6 feet as shown in Tables 2

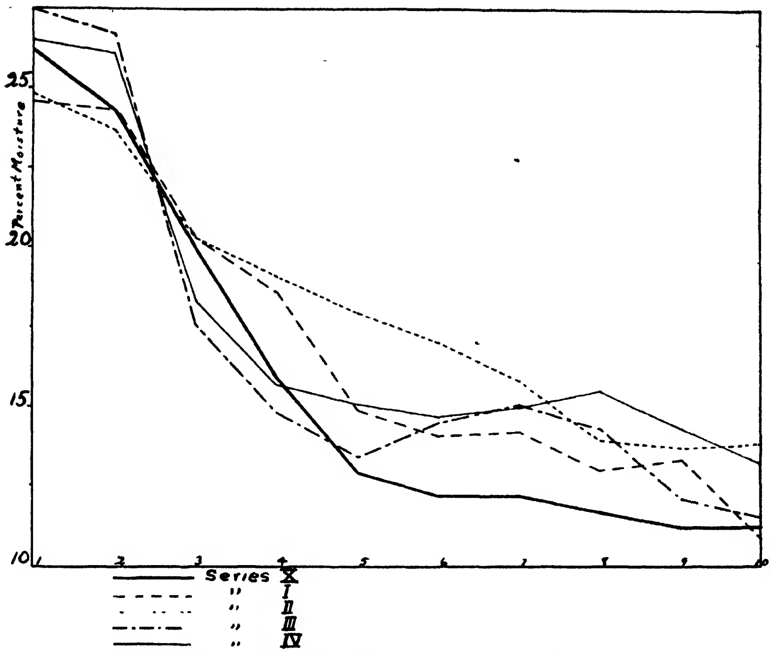


FIG. 2.—The relative amounts of water in the various series November, 1926.

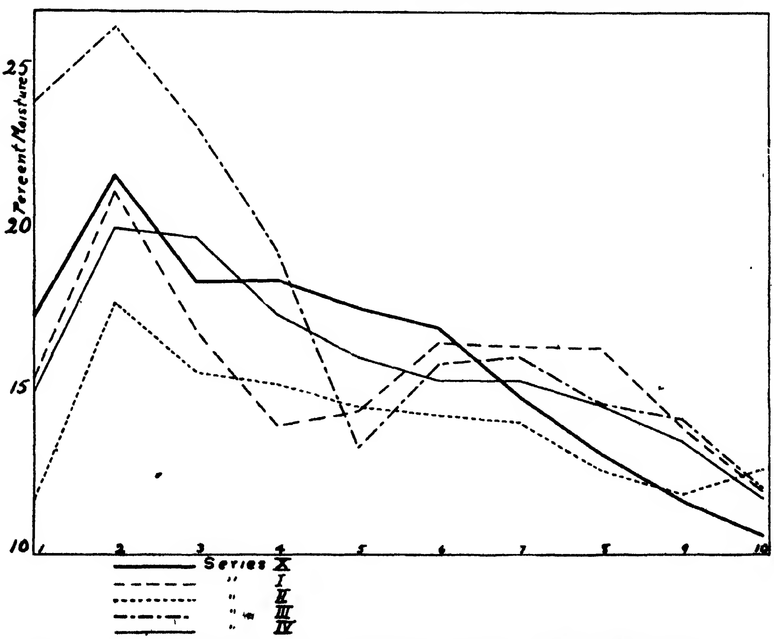


FIG. 3.—The relative amounts of water in the various series May 24, 1928.

to 5 and Figs. 2 and 3. In fact the only noteworthy increase occurred in plat 1 of series I during the fall of 1927 when wheat followed wheat and the land was practically idle for several months. The moisture content was then reduced by the wheat crop so that on May 24, 1928, it was approximately the same as in the fall of 1926. Plat 1 of series III, which was also in wheat during 1927, did not show the increase in subsoil moisture as did series I. This can probably be accounted for by the fact that it was not plowed until late in the fall and there was considerable weed growth during the summer, and perhaps also because it has a little more slope than series I and probably lost more water by runoff.

TABLE 2.—*Percentage of moisture of plat 1, series I, in a 16-year rotation.*

| Depth in feet | Crop and date of sampling: Wheat after corn Nov. 13, 1926 | Wheat after wheat, Nov. 26, 1927 | Wheat, May 24, 1928 | Wheat stubble, Aug. 28, 1928 |
|---|---|---|---|---|
| 1 | 24.6 | 20.9 | 15.5 | 19.9 |
| 2 | 24.3 | 28.8 | 21.3 | 26.5 |
| 3 | 20.3 | 24.7 | 17.0 | 22.8 |
| 4 | 18.6 | 22.8 | 14.0 | 18.1 |
| 5 | 14.9 | 22.2 | 14.4 | 16.1 |
| 6 | 14.1 | 22.0 | 16.6 | 14.4 |
| 7 | 14.2 | 17.5 | 16.5 | 14.7 |
| 8 | 13.0 | 16.5 | 15.9 | 13.3 |
| 9 | 13.3 | 12.9 | 13.9 | 12.0 |
| 10 | 10.8 | 11.9 | 11.9 | 10.2 |
| Average 10 feet | 16.8 | 20.0 | 15.7 | 16.8 |
| Average 0–5 feet | 20.5 | 23.9 | 16.4 | 20.7 |
| Average 6–10 feet | 13.1 | 16.2 | 15.0 | 12.9 |

The moisture in the upper 5 feet of soil, except for the first determination, has been decidedly lower in plat 1 of series II carrying alfalfa than in any of the other series, but the average in the deeper subsoil has been much the same, as indicated in Tables 2 to 5.

It is of interest to note also that series IV which was broken out of alfalfa sod in the fall of 1917 shows only slight variation in moisture content from the other series. This indicates that it did not accumulate any significant amount of moisture in the lower subsoil while in corn and wheat.

That these soils were able to absorb more water without losing it by drainage is indicated by the moisture equivalent determinations as given in Table 6. It would appear from these results that when the whole 10-foot section is considered there has been no time when the soil could not have held more water if it had been present.

TABLE 3.—*Percentage moisture of plat 1, series II, in a 16-year rotation.*

| Depth in feet | Crop and date of sampling | | | |
|---|---|---|---|---|
| | Alfalfa, Nov. 13, 1926 | Alfalfa, Nov. 26, 1927 | Alfalfa, May 24, 1928 | Alfalfa, Aug. 28, 1928 |
| 1 | 24.8 | 14.1 | 11.7 | 18.1 |
| 2 | 23.7 | 19.6 | 17.8 | 20.4 |
| 3 | 20.3 | 16.3 | 15.7 | 16.8 |
| 4 | 19.1 | 17.0 | 15.3 | 14.9 |
| 5 | 17.9 | 16.1 | 14.6 | 13.5 |
| 6 | 17.0 | 14.7 | 14.3 | 13.5 |
| 7 | 15.8 | 16.1 | 14.1 | 14.0 |
| 8 | 13.9 | 14.4 | 12.6 | 13.2 |
| 9 | 13.7 | 13.5 | 11.8 | 12.9 |
| 10 | 13.8 | 12.9 | 12.6 | 12.2 |
| Average 10 feet | 18.0 | 15.5 | 14.1 | 14.9 |
| Average 0–5 feet | 21.2 | 16.6 | 15.0 | 16.7 |
| Average 6–10 feet | 14.8 | 14.3 | 13.1 | 13.2 |

TABLE 4.—*Percentage moisture of plat 1, series III, in 16-year rotation.*

| Depth in feet | Crop and date of sampling | | | |
|---|---|---|---|---|
| | Wheat after wheat, Nov. 13, 1926 | Wheat land plowed for corn, Nov. 26, 1927 | Corn, May 24, 1928 | Corn, Aug. 28, 1928 |
| 1 | 27.5 | 19.4 | 24.2 | 22.2 |
| 2 | 26.7 | 27.7 | 26.5 | 22.4 |
| 3 | 17.6 | 21.8 | 23.4 | 19.9 |
| 4 | 14.8 | 16.1 | 19.5 | 16.9 |
| 5 | 13.4 | 15.6 | 13.3 | 14.9 |
| 6 | 14.5 | 14.8 | 15.9 | 15.0 |
| 7 | 15.1 | 16.1 | 16.2 | 15.1 |
| 8 | 14.3 | 14.7 | 14.7 | 14.4 |
| 9 | 12.1 | 13.7 | 14.2 | 12.6 |
| 10 | 11.5 | 12.7 | 12.0 | 11.5 |
| Average 10 feet | 16.8 | 17.3 | 18.0 | 16.5 |
| Average 0–5 feet | 20.0 | 20.1 | 21.4 | 19.3 |
| Average 6–10 feet | 13.5 | 14.4 | 14.6 | 13.7 |

## DISCUSSION OF RESULTS

The principal thing brought out so far by this work is that under climatic conditions prevailing at Manhattan, Kansas, alfalfa on upland must make most of its growth after the first few years at least from the rainfall as it comes. The amount of moisture in the subsoil of land in continuous alfalfa has been so low that it has not supplied the needs of the crop during severe droughts. At such times growth has been almost completely suspended. A similar but slightly less marked effect has been noted on the alfalfa in rotation. The roots may have extended considerably below 10 feet, the depth of the samples, but if any moisture was brought from below this depth, it was

TABLE 5.—*Percentage of moisture of plat 1, series IV, in 16-year rotation.*

| Depth in feet | Crop and date of sampling: Wheat land plowed for corn, Nov. 13, 1926 | Wheat after corn, Nov. 26, 1927 | Wheat, May 24, 1928 | Wheat land plowed Aug. 6, sampled Aug. 28, 1928 |
|---|---|---|---|---|
| 1 | 26.5 | 14.4 | 15.1 | 26.1 |
| 2 | 26.1 | 22.4 | 20.2 | 28.7 |
| 3 | 18.3 | 21.0 | 19.9 | 23.1 |
| 4 | 15.7 | 18.5 | 17.5 | 20.0 |
| 5 | 15.1 | 18.9 | 16.2 | 16.1 |
| 6 | 14.7 | 16.3 | 15.4 | 14.8 |
| 7 | 15.0 | 17.5 | 15.4 | 15.3 |
| 8 | 15.5 | 16.0 | 14.7 | 15.3 |
| 9 | 14.3 | 14.7 | 13.5 | 14.4 |
| 10 | 13.2 | 12.6 | 11.7 | 13.2 |
| Average 10 feet | 17.4 | 17.2 | 16.0 | 18.7 |
| Average 0–5 feet | 20.3 | 19.0 | 17.8 | 22.8 |
| Average 6–10 feet | 14.5 | 15.4 | 14.1 | 14.6 |

not sufficient to produce much growth during a severe drought. When rains come to moisten the surface soil growth is resumed. Even with above normal rainfall, as during the latter part of 1926 and the seasons of 1927 and 1928, there was no material increase in deep subsoil moisture.

TABLE 6.—*Moisture equivalent determinations.*

| Depth in feet | Moisture equivalent: Continuous alfalfa | 16-year rotation |
|---|---|---|
| 1 | 25.4 | 18.3 |
| 2 | 30.3 | 32.9 |
| 3 | 29.0 | 30.9 |
| 4 | 28.5 | 28.9 |
| 5 | 26.5 | 26.3 |
| 6 | 22.2 | 25.1 |
| 7 | 21.9 | 27.8 |
| 8 | 21.5 | 26.3 |
| 9 | 24.3 | 23.6 |
| 10 | 24.9 | 22.4 |

One reason for so little accumulation of moisture in the lower subsoil is that most of the rainfall comes during the growing season. With a higher winter precipitation the moisture would perhaps have time to sink into the ground before being taken out by the crop. Since the average monthly precipitation for the five months November to March is only 1.18 inches, there is not much opportunity except in certain years for increase in subsoil moisture during this period.

The results in the 16-year rotation would indicate that, if after breaking up alfalfa, land is kept in other crops, such as corn and wheat, the subsoil will gain moisture very slowly. Series IV, which has been out of alfalfa since 1917, has not accumulated any deep subsoil moisture above that contained in land broken out of alfalfa in 1925. In other words, land may be in no better condition, so far as moisture content is concerned, after several years rotation with other crops than immediately after it is broken out of alfalfa. If the stands of alfalfa are more easily obtained following such a rotation, and practical experience would seem to indicate that they are, the reason would seem to include some factor or factors other than moisture.

When the alfalfa sod was plowed in June 1928, both the upper soil and deep subsoil gained rapidly in moisture. None of the other series carrying crops gained materially in subsoil moisture during this period. It would appear from this that fallowing is a rapid method of increasing the moisture content of both the surface layers and the deep subsoil.

## SUMMARY

1. At the Kansas Experiment Station soil moisture determinations to a depth of 10 feet have been made during the seasons of 1926 to 1928 on upland that has been in alfalfa since 1910 and also on land in a 16-year rotation including 4 years of alfalfa.

2. When alfalfa was on the land the moisture content of the deep subsoil was reduced to a low point and remained almost constant.

3. With most of the rainfall coming during the growing season, the moisture penetrated very slightly below a depth of 6 feet. The crop used the moisture about as fast as it came.

4. When alfalfa land in the 16-year rotation was broken and kept in corn and wheat for 10 years, the deep subsoil failed to gain materially in moisture.

5. When a field in alfalfa for 18 years was broken out June 6, 1928, and fallowed until August, both the soil and the deep subsoil gained rapidly in moisture, whereas other land carrying a crop made no gain during this period. This would tend to emphasize the value of at least a short period of fallowing to conserve moisture for getting alfalfa started.

# INTERPRETING CORRELATION COEFFICIENTS[1]

FREDERICK D. RICHEY[2]

A note on, "The Formula for Interpreting the Correlation Coefficient," in this JOURNAL for September,[3] calls attention to two methods that have been used for estimating the portion of the variability in a dependent variable ($X$) that is due to variability in a correlated independent variable ($Y$). It is shown that $r^2_{XY}$ (or $R^2_{X\cdot Y}$, if $Y$ represents two or more variables) measures "the proportion of the total squared variability" in the dependent variable, $X$, due to the independent variable $Y$. Apparently, this demonstration is assumed to prove "the error in the use of this formula," i.e.,

$$100\ (1-\sqrt{1-r^2_{XY}}) \qquad (1)$$

"as a means of measuring the proportion of total variability which may be accounted for by a given correlation coefficient." Writing

$$100\ r^2_{XY} \qquad (2)$$

puts the $r^2$ method on a percentage basis comparable with (1).

The demonstration of (2) as measuring the percentage of "the total squared variability" in $X$ due to $Y$ cannot be questioned, if "total squared variability" is synonymous with "squared standard deviation." Accepting this synonymy leads directly to considering the "total variability" in $X$ as synonymous with the standard deviation of $X$. This, too, seems logical. As a consequence, however, the demonstration of (2) as a correct expression for the portion of the squared variability in $X$ due to $Y$ proves equally the soundness of (1) as a measure of the portion of the variability in $X$ due to $Y$, rather than proving (1) in error as apparently is assumed.

The difficulty arises in confusing the condition of variability with an arbitrary measure of this condition. The degree to which variability obtains may be measured in several ways. Thus, the extreme range, the interdecile range, the average deviation, and other measures of variability may be used conveniently and appropriately in some cases. Probably the most commonly used measure of variability, however, is the standard deviation for which the customary symbol is $\sigma$. More recently, R. A. Fisher has introduced the very convenient term variance to designate $\sigma^2$, the squared standard deviation.

[1]Contribution from the Office of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture, Washington, D. C. Received for publication December 9, 1928.

[2]Senior Agronomist in Charge of Corn Investigations.

[3]IMMER, F. R. Jour. Amer. Soc. Agron., 20:988–989. 1928.

Now ${}_Y\sigma_X$, the standard deviation of *X* when the effect of variation in *Y* has been eliminated, may be had from the equation

$$ {}_Y\sigma_X = \sigma_X \sqrt{1 - r^2_{XY}} \qquad (3)$$

As this is the standard deviation remaining in *X* after *Y* has been made constant, the influence of *Y* is given by

$$\sigma_X - \sigma_X \sqrt{1 - r^2_{XY}} \qquad (4)$$

which, divided by $\sigma_X$ and multiplied by 100, gives formula (1), the percentage reduction in the standard deviation of *X* that is accomplished by eliminating the effect of variation in *Y*. This, of course, is the percentage variability in *X*, as measured by the standard deviation, due to *Y*. This measure is entirely sound and has value for certain purposes. Thus, formula (1) may be used in predicting the standard deviation (or probable error) of a variable after adjustment to its regression on a correlated variable, thereby eliminating the effect of correlated variation. In view of the fact that the standard deviation long has been practically the exclusive standard measure of variability in studies involving the use of correlation coefficients, the insertion of, "as measured by the standard deviation," seems unnecessary except as special conditions make the statement otherwise ambiguous.

The variance of *X* when *Y* is made constant is had from the square of equation (3), i.e.

$$ {}_Y\sigma^2_X = \sigma^2_X \, (1 - r_X{}^2{}_Y) \qquad (5)$$

Subtracting from $\sigma^2_X$, analogously to the treatment of (3), we get

$$\sigma^2_X \, r^2_{XY} \qquad (6)$$

which, divided by $\sigma^2_X$ and multiplied by 100, gives formula (2), the percentage of the variance of *X* that is eliminated by making *Y* constant, or the percentage variance of *X* due to *Y*. In most cases such a statement should be sufficiently clear. Should it be desirable to emphasize that variance is one measure of variability, formula (2) may be interpreted as measuring the variability of *X*, as measured by its variance, due to *Y*.

The analysis of correlated variation in terms of variance probably has a much wider field of usefulness than that in terms of the standard deviation. The latter does have some place, however, and there formula (1) should be used. To refer to formula (1) as an erroneous measure of the portion of the total variability in the dependent variable due to that in the independent variable, and to use the definite article in describing $r^2$ as "the formula for interpreting the correlation coefficient" is misleading.

Each formula is correct and each has its place. The choice must depend upon the nature of the problem and the terminology should make that choice clear.

## A REPLY BY F. R. IMMER

In his criticism of a note by the writer on "The Formula for Interpreting the Correlation Coefficient" published in this JOURNAL (Vol. 20:988–989), Richey agrees that $R^2$, expressed in per cent, may be properly used as a measure of the proportion of total squared variability (as measured by the variance or squared standard deviation) in a dependent variable which may be explained in terms of its mathematical relations to the independent variables considered in calculating the given correlation coefficient; or, in other words, the percentage of the variance of the dependent variable that is eliminated when the effect of the independent variables is held constant. Richey shows that the formula $100\ (1-\sqrt{1-r^2})$ has value for certain purposes, which was not denied in my original paper.

The writer is in entire agreement that both formulae have their place and neither should be entirely overlooked or ignored. The formula to which the most attention must be paid in a particular investigation depends upon the phase of the investigation which is most important; the *amount* of reduction in variability expressed by the standard deviation of the predicted values as compared with that of the original values taken about their mean, or the *proportionate* importance of a given variable or set of variables on the dependent variable.

In his original paper the writer dealt primarily with the latter problem for which $R^2$, expressed in per cent, seems to be the more logical formula, although the use of the formula $100\ (1-\sqrt{1-r^2})$ was pointed out. $R^2$ has the added advantage that the amount of total squared variability (as measured by the variance) not accounted for may be obtained by subtracting the value of $R^2$ from unity. The formula $100\ (1-\sqrt{1-r^2})$ bears no such simple relationship to the amount of variability not accounted for.

## NOTE

### THE RELATION OF SHUCK COVERING TO EAR-WORM ATTACK

Long shuck covering has been said to be a fair measure of protection against insects attacking corn in field or crib. The practice in the South has been to store corn in the shuck to reduce weevil damage. There can be no question but what the shucks do protect against weevils, angoumois moths, and perhaps other insects attacking stored corn. The only other measure of protection available is fumigation with carbon disulfide, which necessitates very tight cribs and introduces a fire hazard.

The weevils attack the corn with little or no shuck covering or the ears where an entrance has been made for them by the ear-worm through the silk-channel or through the hole in the shucks through which the worm made his exit. If corn is protected by long shucks and unattacked by ear-worm, then weevils and moths can do little damage to it.

Kyle[1] advocates selection of corn for long shuck covering as a means of reducing damage by the weevils, wet weather, and molds, incidently also, by the ear-worm, saying, "That when there is a long shuck extension, the worms frequently cut from the silk channels before reaching the ear and the longer the extension, the more frequently this happens." He found[2] that with long shuck extension the worms cut from silk channels in 7% more instances than where the shuck covering was short. He gives the percentage of ears attacked by worms as follows:

| | |
|---|---|
| With shuck extension of 4 to 6 inches | 72% |
| With shuck extension of 2 to 3 inches | 87% |
| With no shuck extension | 96% |

These observations were made in south Georgia and may be taken as more or less true for all cotton belt sections. That there may be variations, however, is shown by some observations of the writer made in north Arkansas in 1928 on open-pollinated ears of selfed strains of different varieties and also on open-pollinated ears of Paymaster corn. The selfed varieties included Hasting's Prolific, Jarvis Golden Prolific, Mexican June, Reid's Yellow Dent, Champion White Pearl, Pride of Saline, and Paymaster. To compare corn of open-pollinated ancestry and to see if selfed strains were more subject to ear-worm attack, some observations on an adjoining field and also on a distant field of Paymaster corn were made. The results given in Table 1 are much the same as in the selfed strains.

[1]Kyle, C. H. How to reduce weevil waste in southern corn. U. S. D. A. Farmers' Bul. 915. 1918.

[2]———. Shuck protection for ear corn. U. S. D. A. Bul. 708. 1918.

TABLE 1.—*Relation of ear-worm attack to shuck extension on Paymaster corn and on several varieties of selfed corn, 1928.*

| | Nature of attack | Number of ears examined | Extension of shuck covering in inches 1.5 | 2 | 2.5 | 3 | 3.5 | 4 | 4.5 or more | Percentage |
|---|---|---|---|---|---|---|---|---|---|---|
| Strains of selfed corn | Number of ears:...... | 485 | | | | | | | | |
| | (a) not attacked.... | 14 | | 2 | 5 | 5 | | | 2 | 2.89 |
| | (b) attacked but not entered...... | 12 | | | 3 | 3 | 1 | 1 | 4 | 2.47 |
| | (c) fully entered.... | 459 | 13 | 57 | 85 | 90 | 78 | 63 | 73 | 94.64 |
| Adjoining field Paymaster | Number of ears:...... | 109 | | | | | | | | |
| | (a) not attacked.... | | | | | | | | | |
| | (b) attacked but not entered...... | 1 | | | | | 1 | | | 0.92 |
| | (c) fully entered.... | 108 | 13 | 24 | 23 | 17 | 9 | 7 | 15 | 99.08 |
| Distant field Paymaster | Number of ears:...... | 444 | | | | | | | | |
| | (a) not attacked.... | 7 | | 1 | 1 | 2 | | | 3 | 1.58 |
| | (b) attacked but not entered...... | 10 | | | | 2 | | 1 | 7 | 2.25 |
| | (c) fully entered.... | 427 | 34 | 82 | 75 | 95 | 38 | 49 | 54 | 96.17 |

In the selfed strains if the ears having an extension of 4 inches or more be considered separately, the percentage of ears entered is 95.1%. The numbers counted in the adjoining field being small, the greater attack is of no significance. In the Paymaster fields less than 2.5% were abandoned by the worms as in the selfed strains. In the distant field there is greater tendency to "cut out" in ears having the 4 inches or more of shuck extension, this amounting to 7.7%.

The sum total of ears examined was 1,038. The number entered was 994, or 95.76%, of the total. The sum total of ears having shuck extension of 4 inches or more was 279 and the number entered was 261, or 93.55% of this total.

These observations are given as showing the completeness of attack in 1928. They seem to indicate that little protection is offered by the long shucks in a season when the attack is so universal. However, since long shucks protect the ears against weevils and against wet weather and molds as brought out by Kyle, the data should not lead anyone to favor short shuck extension. Moreover, O'Kelley, et al[3] have found that yields from corn with long shuck covering exceeds the yields from corn with short husks by 2.3 bushels per acre—in itself, a fact worth considering.—C. K. MCCLELLAND, *Department of Agronomy, Arkansas Agricultural Experiment Station, Fayetteville, Ark.*

[3]O'KELLY, J. F., et al. Miss. Agr. Exp. Sta. Ann. Rpt. 1924.

## BOOK REVIEW

### DAS KLIMA DER BODENNAHEN LUFTSCHICHT (THE CLIMATE OF THE ATMOSPHERIC LAYER NEAR THE SOIL)

*By Dr. Rudolf Geiger, Privatdozent an der Universität München. Friedr Vieweg & Sohn Akt Ges. XII +246 pp., illus. 1927.*

The meteorologic and climatic conditions of that layer of the atmosphere in which most common agricultural crops grow has been practically neglected in most meteorological and climatological studies. In an excellent little text book written with true Teutonic thoroughness Geiger has summarized most of the available basic principles. The first section on the "Physics of the atmospheric layer near the soil" provides the scientific basis for the three succeeding sections, namely, "Orographic Microclimatology", "Special Plant Climatology," and "Frost Damage in the Air Layer Near the Soil."

The first section considers such topics as the following: (1) The significance of the soil surface in the heat exchanges at midday; (2) the temperature distribution at midday; (3) heat conduction and exchange; (4) heating processes and temperature fluctuation; (5) heat changes and temperature distribution at night; (6) the daily course of temperature in the atmospheric layer near the soil; (7) the humidity of the atmospheric layer near the soil; and (8) the wind velocity in the atmospheric layer near the soil.

The second section shows how the climate of the atmospheric layer near the soil is influenced by the orographic conformation of the earth's surface. The author discusses such subjects as the movement of cold air and the relation of angle of exposure to climate.

The third section deals with such subjects as effect of different soil and vegetation surfaces upon the proportion of a low vegetal cover; humidity and air movements in a low vegetal cover; and the meteorology of agriculture, of moors, and of forests.

The fourth section deals with types of frost and factors influencing their appearance, frost forecasts, and artificial protection against frost.

Agronomists and horticulturists, as well as all other students of agricultural meteorology, will find this book worthy of their closest study. (H. L. W.)

## AGRONOMIC AFFAIRS

### MEETING OF THE NEW ENGLAND SECTION

The fifteenth annual meeting of the New England Section of the American Society of Agronomy was held in New York, December 28, 1928; being a joint meeting between the Section and Section O of the American Association for the Advancement of Science. The program of the meeting was rendered practically as printed in the December number of the JOURNAL. Approximately 100 persons attended the subject matter symposium on "Pasture Management Research," and some 60 were present at the banquet. New officers

were elected for the New England Section: Henry Dorsey of the Connecticut Agricultural College, at Storrs was elected Chairman of the New England Section for 1929, and M. H. Cubbon of the Massachusetts Agricultural College, at Amherst, Secretary.

## ON THE USE OF BOTANICAL NAMES IN THE JOURNAL

We are in receipt of the following suggestion from a New Zealand reader of the JOURNAL, which, in our estimation, deserves consideration in future articles appearing in the JOURNAL:

"I would beg to suggest that your contributors be asked to state once in the course of an article the botanical name of any plant mentioned. I have noticed several instances of this omission and now especially refer to the article on the eradication of quack grass appearing on Page 1120 of Volume 20 of the JOURNAL. For want of knowing what grass bears the trivial name of quack grass, the article becomes meaningless to many of your readers."

## NEWS ITEMS

OLAF S. AAMODT returned on October 10 from Europe where he spent nearly four months in a study of plant breeding methods for disease resistance in cereal crops at the important experiment stations of western Europe. Dr. Aamodt, who was formerly associated in the cooperative wheat improvement program of the U. S. Department of Agriculture and the Minnesota Agricultural Experiment Station at University Farm, St. Paul, Minnesota, is now geneticist and plant breeder at the University of Alberta, Edmonton, Alberta, Canada.

LEWIS W. ERDMAN, Professor of Soils at Maryland University, and formerly Assistant Professor of Soils and Assistant Chief in Soil Bacteriology at the Iowa State College, has been appointed head of the bacteriological research and production departments of the Nitragin Company of Milwaukee.

PRESIDENT FUNCHESS has appointed H. R. Sumner of Minneapolis, Minn., representative of the Society on the Seed Council of North America.

ADRIAN DAANE, former Professor and Head of the Department of Field Crops and Soils at Oklahoma, is taking graduate study in Plant Genetics at the University of Minnesota.

C. K. MCCLELLAND, Assistant Professor and Assistant Agronomist at Arkansas, spent several months at Minnesota in the Division of Agronomy and Plant Genetics, studying genetic and breeding work at that station.

THE MINNESOTA SEED GROWER, at present a 4-page publication issued bi-monthly, has become the official organ for the Minnesota Crop Improvement Association with Dr. Andrew Boss as Editor and Manager. This publication replaces a similar one published by the Red River Valley Crops and Soils Association.

On July 1 the former Division of Farm Management, Agronomy, and Plant Genetics of the University of Minnesota was disintegrated into two divisions. Agronomy and Plant Genetics was established as a single division with Dr. H. K. Hayes serving as chief. The Farm Management section was merged with Agricultural Economics into the Division of Farm Management and Agricultural Economics, with Dr. O. B. Jessness, formerly in charge of the marketing division of the Kentucky Agricultural College and Experiment Station, in charge. Dr. Andrew Boss, who had served as chief under the old division name of Farm Management, Agronomy, and Plant Genetics, was released from the duties of the chiefship in order that he might give his time as Vice-Director of the Experiment Station more specifically to the organization and conduct of the Experiment Station work.

On October 10, representatives of various agencies interested in and engaged in the seed trade in Minnesota met with the agronomists and the extension agronomists at University Farm to consider the organization of a State Seed Council. The idea prompting the Council is to secure united action on the part of these various agencies in promoting the standardization of varieties adapted to the state and in securing cooperation through sales and distribution agencies in encouraging the use of seed of known quality. While the Council was not clothed with authority of any kind, it is believed that it will serve a useful function in stimulating the production of pure seed and in the distribution of strains and varieties adapted to various parts of Minnesota.

R. E. Stitt, former assistant in Agronomy at Minnesota, has taken up his work as assistant in Agronomy at the Massachusetts Agricultural College.

At the annual business meeting of the Iowa Section of the American Society of Agronomy, the following officers were elected for the year: President, J. B. Wentz; Vice-President, E. R. Henson; Secretary-Treasurer, H. R. Meldrum.

Arthur O. Alben, formerly research fellow in soils at the Iowa State College, has been appointed Assistant Soil Technologist in the Bureau of Chemistry and Soils, U. S. Dept. of Agriculture. His work will be chiefly on soil fertility investigations in pecan groves in the southern states, under the direction of Dr. Oswald Schreiner of the Division of Soil Fertility.

Ralph T. Stewart, Associate Professor of Agronomy at the Texas Agricultural and Mechanical College, received the Ph.D. degree at the Iowa State College in August and returned to his duties in Texas.

T. S. Buie received the Ph.D. degree at the Iowa State College in August and returned to his duties as Professor of Agronomy and Agronomist at the Clemson College and Experiment Station after a year's leave of absence from that institution.

Dr. Theodore E. Odland, formerly Associate Agronomist at the West Virginia Agricultural Experiment Station, has been appointed

Agronomist at the Rhode Island Agricultural Experiment Station to succeed Dr. B. L. Hartwell, effective February 1. Dr. B. E. Gilbert, formerly Chemist at the Rhode Island Station, has been Director.

J. H. STALLINGS, formerly agronomist for the J. C. Penny-Gwinn Corporation at Penny Farms, Florida, has accepted a position with the Soil Improvement Committee of the National Fertilizer Association with headquarters at Shreveport, Louisiana.

ROY D. HOCKENSMITH, of the University of Missouri, has been appointed Associate Professor of Agronomy in charge of soils work at Fort Collins, Colo. He reported for service January 10.

ROBERT GARDNER has been appointed Associate Chemist in charge of soil work at the Rocky Ford Experimental Farm, Rocky Ford, Colorado, effective February 1.

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# THE SIGNIFICANCE OF SUBSOIL MOISTURE IN ALFALFA PRODUCTION[1]

T. A. KIESSELBACH, J. C. RUSSEL, AND ARTHUR ANDERSON[2]

## INTRODUCTION

Alfalfa produces remarkable yields at the Nebraska Agricultural Experiment Station during the first three or four years on land growing this crop for the first time. In this initial period the yields are practically independent of the amount of rainfall. Thereafter, they decline and become largely dependent upon the precipitation. On land that has previously grown alfalfa, even as remote as 15 years, the yields appear dependent upon rainfall from the very beginning and are never as high as during the early years on land where this crop has not previously been grown. Many farmers on the unirrigated uplands of Nebraska report the same experiences. The explanation for this and what can be done about it is becoming a matter of considerable concern.

The attention of the writers was forcibly directed toward this problem in 1921 when a series of alfalfa plats was sown at the Experiment Station farm in a field that had in part been in alfalfa nine years previously. Though an equally good stand was obtained in both portions, growth was invariably poorer where alfalfa had formerly grown. During the last three of the four years that this crop was allowed to stand, that portion previously in alfalfa yielded 2.07 tons of cured forage per acre, while the other portion averaged 3.75 tons per acre.

In 1925 a corresponding series of plats was planted to alfalfa adjacent to the first series in the same field. The performance was much the same, the average acre yield for the years 1926 and 1927 being 1.36 and 3.83 tons, respectively, on the two portions.

[1]Contribution from the Department of Agronomy, Nebraska Agricultural Experiment Station, Lincoln, Nebr., as paper No. 68, Journal series. Published with the approval of the Director. Received for publication January 2, 1929.

[2]Agronomists.

Another series of plats wholly on land never before occupied by alfalfa has been in existence since 1922. This yielded bountifully for the first few years, the maximum production being more than 7 tons per acre in 1924. Yields fell off sharply in 1926, and during 1926 and 1927 averaged only 2.0 tons per acre. Characteristics of growth during the latter years corresponded closely to those exhibited by alfalfa on land that had grown alfalfa before, which suggests the same cause for reduced production in the two cases.

In connection with the first two series mentioned above, a variety of applications of manure, commercial fertilizers, gypsum, and lime were tested on that portion of the field previously in alfalfa. Little benefit was secured from any treatment. Any theory that the reduced production is due to depletion of mineral nutrients is therefore untenable.

It was early perceived that a more likely explanation of the reduced yields lay in a depleted subsoil moisture supply. Alfalfa has a high water requirement. Its roots penetrate deeply into the subsoil and the water obtained therefrom undoubtedly contributes to growth in large measure. It does not appear unreasonable that when subsoil moisture becomes largely depleted yields should decline. Furthermore, when alfalfa is reseeded on land that it has previously occupied, low yields are to be expected if the moisture of the subsoil is unrestored, and in regions where moisture is a limiting factor in grain crop production replenishment of the subsoil water content may be a slow process.[3]

With these points in mind, soil sampling was begun at the Experiment Station farm in such fields as had desirable historical background with respect to alfalfa culture. The first samples were taken in 1924 to depths of 15 feet. Later the depth of sampling was increased to 35 feet in cases, and studies were enlarged to include artificial watering, root excavations, and an analysis of crop yields.

It is the purpose of this paper to present the data thus obtained bearing upon (a) the problem of depletion of subsoil moisture by alfalfa in relation to its productivity under upland conditions of limited rainfall and non-irrigation, and (b) upon the rate of restoration of this subsoil moisture under ordinary cropping systems, and the possibilities of re-establishing a productive alfalfa meadow on land previously in this crop.

[3]This explanation is the outgrowth of investigations, experiences, and observations of various workers associated with agronomic problems at the Nebraska Agricultural College. The extensive soil moisture studies of Director W. W. Burr, begun at the North Platte Substation as early as 1907, have been a material contribution.

## DESCRIPTION OF FIELDS

The study of these subsoil moisture relations has been confined to the Nebraska Agricultural Experiment Station farm at Lincoln. Meadows of various ages and conditions of cropping and fields farmed to cereal crops for various periods since breaking up from alfalfa and fields never cropped to alfalfa have here been available for such studies during the last four years. The fields involved and the years when alfalfa was growing on them are shown in Fig. 1. These fields have all been under cultivation approximately 50 years and have always grown non-leguminous crops, mainly corn, oats, and wheat, except for the alfalfa indicated.

All of the alfalfa meadows under consideration carried a good healthy stand of plants throughout the periods of observation. The average annual precipitation at Lincoln is 27.5 inches.

The soil of the experimental farm is mainly Carrington developed on Kansan Drift. The surface is a clay loam quite receptive of moisture. The subsoil of the second and third foot is a tight clay not uncommon in soils in southeastern Nebraska. The subsoil below the third or fourth foot is uniformly a friable silt distinctly free of gravel and much resembling loess to a depth of at least 35 feet, except for an occasional pocket of sand that proves its glacial origin. The slope in areas where samples were taken varies from 0 to about 2%. The depth to permanent water is approximately 100 feet which is quite beyond the reach of alfalfa roots.

A small portion of the farm (Fig. 1, H and I) on which certain samples were taken is Waukesha developed on a nearly level terrace which receives runoff from the higher lying Carrington. Where the samples were taken it is approximately 80 feet to permanent water. The surface soil and deeper subsoil is fairly comparable to that of the upland, but the compact layer is absent.

## METHODS OF SOIL MOISTURE STUDY

Soil samples for moisture determination were taken by foot sections to a depth of 15 feet with ordinary steel soil-sampling tubes. Below the 15-foot level, sampling was continued with a 1¼-inch soil auger. Experimental studies of the technic indicated freedom from any inherent systematic errors.

For each soil sample, the hygroscopic coefficient was determined, using the method of Alway, Klein, and McDole (2)[4]. Tables which follow will show total and free-water contents, the latter being the difference between the total, or field-moisture content, and the hygro-

[4]Reference by number is to "Literature Cited," p. 268.

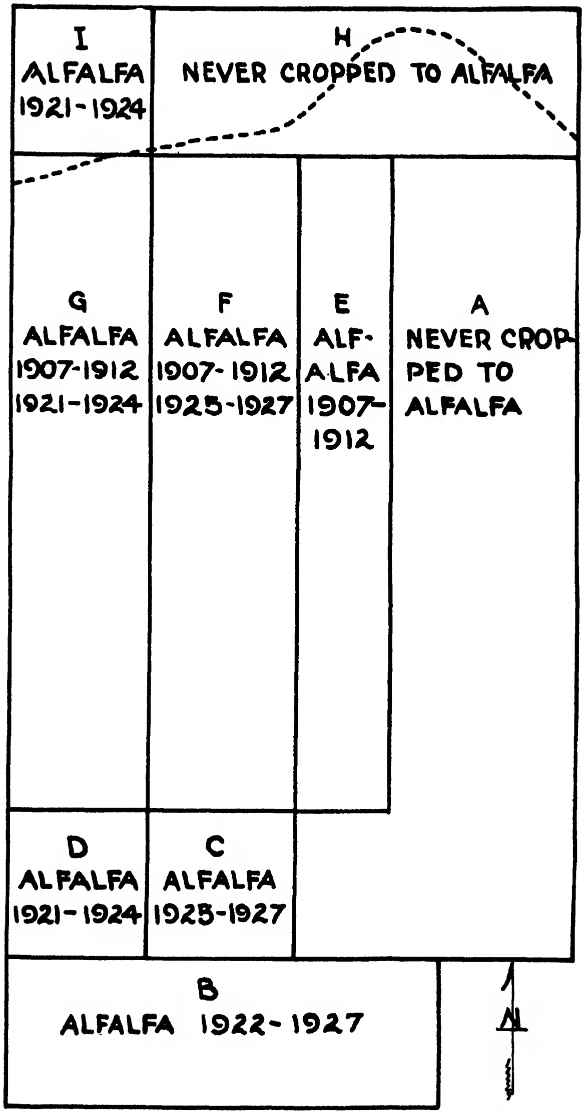


FIG. 1.—Relative location and previous cropping conditions of the various fields or areas on which soil moisture studies were made from 1924–27. In addition there were two other fields approximately 1 mile east from Field B, one of which (J) was in alfalfa from 1926–27 and the other (K) has never been cropped to alfalfa. The broken line running through fields G, I, and H indicates the change from drift soil to soil of alluvial origin. Aside from the alfalfa indicated, the cropping system has included corn, oats, and winter wheat.

scopic coefficient. The calculation of free-water is considered desirable in such studies as these in order to overcome the textural differences that may be encountered at different levels and in different fields. Data shown later indicate that alfalfa may reduce the soil moisture almost to the hygroscopic coefficient, 0.6% being the nearest and 2% being a more common approach. For practical purposes the point of non-availability may be regarded as approximately 2% above the hygroscopic coefficient under these conditions.

## DEPLETION OF SUBSOIL MOISTURE BY ALFALFA

### HISTORICAL

It is generally recognized that the roots of alfalfa extend deeper into the subsoil than do the roots of the cereal crops. Alfalfa is therefore able to use subsoil moisture to lower depths than are the cereals. The average maximum depths of penetration of the roots of oats, winter wheat, and corn (under eastern Nebraska conditions) as reported by Weaver (10) are 4.4, 5.4, and 5 to 6 feet, respectively. The investigations herein reported disclose that under similar conditions alfalfa may extend its roots into the subsoil 30 feet or more.

In a 10-year old alfalfa field in northeastern Nebraska, Alway (1) found that the subsoil moisture was drawn upon to a depth of 33 feet. Between the second and nineteenth foot the free-water had been reduced uniformly to about 2%. In an established alfalfa meadow near Lincoln, Nebr., Alway, McDole, and Trumbull (3) found the subsoil to a depth of 21 feet to be reduced to about 1.1 times the hygroscopic coefficient. This was about half the water content found in adjacent virgin prairie.

Snyder (9) reports that alfalfa on table land at North Platte, Nebr., has been found to reduce soil moisture to 6.4% to a depth of 15 feet, which is as deep as sampling was done. This was on soil capable of retaining around 16% moisture. On similar bench land soil, Burr (4) found that water content was reduced to only 8.5% to a depth of 10 feet, when the roots were able to get capillary moisture from underlying sheet water. Capillary water was apparently definitely drawn upon at 13 feet. The sheet water lay from 4 to 8 feet below this.

Rotmistrov (7) stressed the importance of subsoil moisture for alfalfa and stated that under favorable conditions at Odessa, Russia, alfalfa continued productive five or six years. After that yields were greatly curtailed by moisture deficiency.

Comparing the subsoil moisture to a depth of 15 feet in a four-year-old alfalfa meadow at the Nebraska Agricultural Experiment Station

farm with that in an adjacent wheat field never cropped to alfalfa, Kiesselbach and Anderson (5) found that the alfalfa had lowered the soil moisture content as much as 9% below that of the wheat field at a depth of 15 feet. There was but little difference between the two fields above the fourth foot.

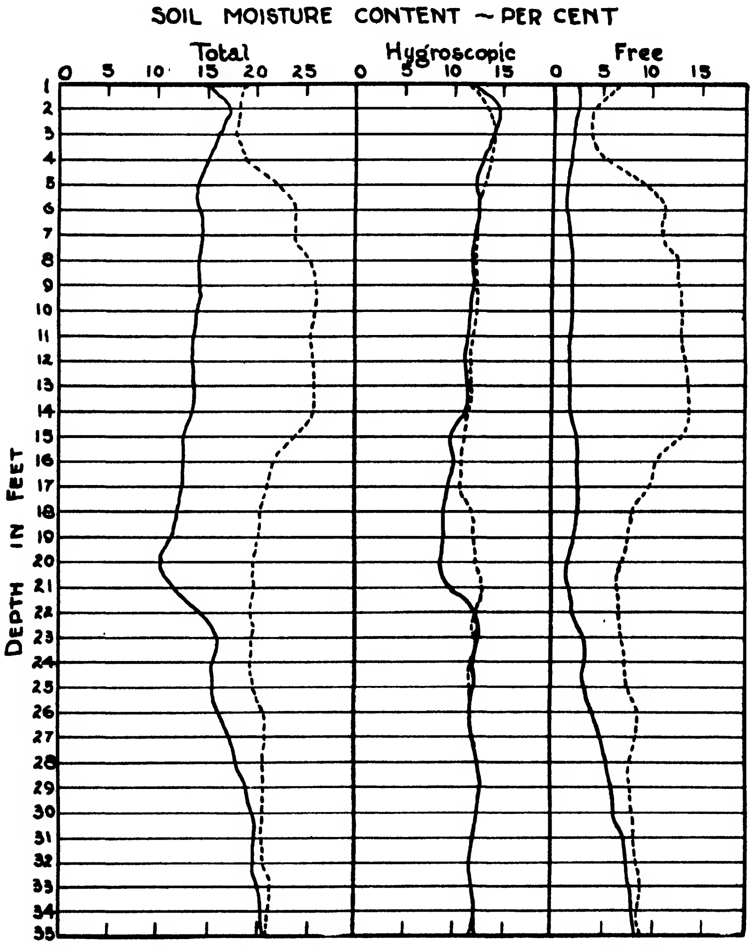


FIG. 2.—Depletion of subsoil moisture by alfalfa during a six-year period. Comparative total moisture (left), hygroscopic moisture (center), and free-water contents (right) in 1927 at 1-foot intervals to a depth of 35 feet in a field cropped to alfalfa during 1922–27 (————) and an adjacent cultivated field which has never been cropped to alfalfa (••••••••). (Data from Table 1.)

## EXPERIMENTAL

### EFFECT OF CROPPING TO ALFALFA DURING SIX YEARS, 1922–27

The oldest alfalfa field (Fig. 1, B) on the experimental farm is one that was sown in 1922. This field began to show a serious decline in yield by 1926. It was sampled at the close of the 1927 season to a depth of 35 feet. For comparison an adjacent cultivated field (Fig. 1, A) which has never been cropped to alfalfa was also sampled. Previous to this alfalfa, the two fields had had essentially the same cropping system. This has been a productive alfalfa meadow, averaging 4.2 tons per acre during the last five years prior to sampling.[5] The moisture data are shown in Table 1 and Fig. 2.

In interpreting the data in this and several similar tables to follow, it is assumed that the moisture conditions found in the deeper subsoil of the cultivated field are stabalized and therefore represent conditions in the alfalfa field at the time it was planted. By deeper subsoil is meant that below 5 feet. General sampling experience indicates that very little water is ordinarily abstracted from below five feet on this farm by crops other than legumes.

The soil in the alfalfa field was found to contain a lower moisture content at all levels than the soil in the adjacent field which had never been cropped to alfalfa. The difference in the upper 4 feet was not very marked, since the corn crop was drawing heavily on this moisture also. The range in the free-water content to a depth of 25 feet was 1.6 to 3.7% in the alfalfa field and 4.1 to 14.2% in the corn field. The averages to this depth were 2.5 and 9.8% for these respective fields. From the twenty-sixth to the thirty-fifth foot inclusive, the free-water increased gradually from 4.5 to 8.5% in the alfalfa meadow, while in the corn field it remained rather constant, fluctuating between 8.1 and 9.3%. As averages of successive 5-foot depths, the alfalfa meadow contained 3.7, 10.4, 11.3, 6.4, 4.3, 2.7, and 0.7%, respectively, less free-water than the adjacent cultivated field.

These data show clearly that the soil moisture in the alfalfa field has been reduced practically to a point of non-availability to a depth of 22 feet. In addition, an appreciable amount of water appears to have been used to a depth of at least 30 feet.

### EFFECT OF CROPPING TO ALFALFA DURING FOUR YEARS, 1921–24

An alfalfa field (Fig. 1, I) located on the terrace and sown to alfalfa for the first time in the spring of 1921 was sampled in the spring of 1925 to a depth of 15 feet. For comparison moisture data

[5]All alfalfa yields given here are calculated to a 15% moisture basis.

from samples taken the preceding fall in adjoining cultivated land never cropped to alfalfa (Fig. 1, H) are used. The data are shown in Table 2. These fields were originally one and are very comparable, except for the cropping to alfalfa. The average annual yield of alfalfa during the three years prior to sampling had been 4.1 tons per acre.

TABLE 1.—*Comparative soil moisture contents to a depth of 35 feet in a field cropped to alfalfa during a six-year period ending in 1927, and in an adjacent cultivated field which had never been cropped to alfalfa.*
Sampled following the 1927 crop.

| Depth of sample in feet | Water content of soil* | | | | Deviation, Column 3 from Column 5 |
|---|---|---|---|---|---|
| | Alfalfa field | | Cultivated field | | |
| | Total % | Free % | Total % | Free % | % |
| (1) | (2) | (3) | (4) | (5) | (6) |
| 1 | 15.3 | 3.4 | 19.1 | 7.2 | —3.8 |
| 2 | 17.9 | 2.8 | 18.5 | 4.7 | —1.9 |
| 3 | 16.5 | 2.4 | 18.3 | 4.1 | —1.7 |
| 4 | 15.5 | 2.2 | 19.4 | 5.6 | —3.4 |
| 5 | 14.2 | 1.6 | 22.5 | 9.3 | —7.7 |
| 6 | 14.7 | 2.0 | 24.4 | 11.8 | —9.8 |
| 7 | 14.9 | 2.4 | 24.2 | 11.3 | —8.9 |
| 8 | 14.6 | 2.4 | 25.8 | 13.3 | —10.9 |
| 9 | 14.7 | 2.4 | 26.2 | 13.4 | —11.0 |
| 10 | 14.3 | 2.3 | 26.4 | 13.7 | —11.4 |
| 11 | 13.8 | 2.1 | 25.8 | 13.4 | —11.3 |
| 12 | 13.9 | 2.2 | 26.0 | 13.8 | —11.6 |
| 13 | 14.0 | 2.3 | 26.0 | 14.0 | —11.7 |
| 14 | 13.9 | 2.2 | 26.0 | 14.2 | —12.0 |
| 15 | 12.9 | 3.0 | 24.3 | 12.7 | —9.7 |
| 16 | 13.4 | 2.9 | 21.9 | 10.8 | —7.9 |
| 17 | 12.7 | 3.0 | 21.3 | 10.3 | —7.3 |
| 18† | 12.1 | 2.8 | 20.5 | 8.3 | —5.5 |
| 19 | 11.5 | 2.4 | 20.2 | 8.0 | —5.6 |
| 20 | 10.2 | 1.6 | 19.9 | 7.3 | —5.7 |
| 21 | 11.8 | 2.0 | 19.8 | 6.7 | —4.7 |
| 22 | 14.8 | 2.6 | 19.5 | 7.2 | —4.6 |
| 23 | 16.2 | 3.7 | 19.8 | 7.2 | —3.5 |
| 24 | 15.5 | 3.4 | 19.6 | 7.7 | —4.3 |
| 25 | 15.7 | 3.4 | 19.7 | 7.8 | —4.4 |
| 26 | 16.5 | 4.5 | 20.8 | 8.7 | —4.2 |
| 27 | 17.5 | 5.2 | 21.0 | 8.9 | —3.7 |
| 28 | 18.2 | 5.7 | 20.7 | 8.1 | —2.4 |
| 29 | 19.0 | 6.4 | 20.7 | 8.2 | —1.8 |
| 30 | 18.9 | 6.5 | 20.6 | 8.3 | —1.8 |
| 31 | 19.6 | 7.6 | 20.5 | 8.5 | —0.9 |
| 32 | 19.8 | 7.9 | 20.6 | 8.6 | —0.7 |
| 33 | 20.5 | 8.4 | 21.4 | 9.1 | —0.7 |
| 34 | 20.7 | 8.5 | 21.1 | 8.9 | —0.4 |
| 35 | 20.9 | 8.5 | 21.1 | 9.3 | —0.8 |

TABLE 1.—*Concluded.*

| | | | | | |
|---|---|---|---|---|---|
| | | Averages of Successive 5-foot Depths | | | |
| 1–5 | 15.9 | 2.5 | 19.6 | 6.2 | —3.7 |
| 6–10 | 14.6 | 2.3 | 25.4 | 12.7 | —10.4 |
| 11–15 | 13.7 | 2.3 | 25.6 | 13.6 | —11.3 |
| 16–20 | 12.0 | 2.5 | 20.8 | 8.9 | —6.4 |
| 21–25 | 14.8 | 3.0 | 19.7 | 7.3 | —4.3 |
| 26–30 | 18.0 | 5.7 | 20.8 | 8.4 | —2.7 |
| 31–35 | 20.3 | 8.2 | 20.9 | 8.9 | —0.7 |

*Moisture content of soil determined from an average of three cores in the case of the alfalfa and six cores for the cultivated field. Other data concerning this alfalfa meadow are recorded in Tables 5, 6, and 7.

†The striking drop in moisture content from the fifteenth to eighteenth foot where alfalfa has not been grown is characteristic of this soil and is in no way related to the manner of sampling as has been determined by special studies in technic.

TABLE 2.—*Comparative soil moisture contents to a depth of 15 feet in a field cropped to alfalfa during four years (1921–24) and in an adjoining field which had never been cropped to alfalfa.*

| Depth of sample in feet | Water content of soil* Alfalfa field sampled in spring, 1925 Total | Free | Cultivated field sampled in fall, 1924 Total | Free | Deviation, Column 3 from Column 5 |
|---|---|---|---|---|---|
| | % | % | % | % | % |
| (1) | (2) | (3) | (4) | (5) | (6) |
| 1 | 29.3 | 20.4 | 19.9 | 10.4 | +10.0 |
| 2 | 21.1 | 10.7 | 20.5 | 8.6 | +2.1 |
| 3 | 17.0 | 3.9 | 17.4 | 3.6 | +0.3 |
| 4 | 18.0 | 4.1 | 17.0 | 2.7 | +1.4 |
| 5 | 17.1 | 3.3 | 17.6 | 3.4 | —0.1 |
| 6 | 16.9 | 3.4 | 19.7 | 5.9 | —2.5 |
| 7 | 16.1 | 3.4 | 22.4 | 9.3 | —5.9 |
| 8 | 16.5 | 3.7 | 24.2 | 11.3 | —7.6 |
| 9 | 16.5 | 4.0 | 25.2 | 12.7 | —8.7 |
| 10 | 17.0 | 4.2 | 27.4 | 13.9 | —9.7 |
| 11 | 17.6 | 4.9 | 26.8 | 13.4 | —8.5 |
| 12 | 17.8 | 5.1 | 27.2 | 13.8 | —8.7 |
| 13 | 17.2 | 5.1 | 26.8 | 13.7 | —8.6 |
| 14 | 16.7 | 4.9 | 26.1 | 13.6 | —8.7 |
| 15 | 17.1 | 4.9 | 26.9 | 13.9 | —9.0 |
| | | Averages of Successive 5-foot Depths | | | |
| 3–5 | 17.4 | 3.8 | 17.3 | 3.2 | +0.6 |
| 6–10 | 16.6 | 3.7 | 23.8 | 10.6 | —6.9 |
| 11–15 | 17.3 | 5.0 | 26.8 | 13.7 | —8.7 |

*Moisture content of soil determined from an average of four cores. The upper 2 feet in these two fields are not comparable because the alfalfa meadow was sampled in the early spring and the cultivated field was sampled late in the previous fall. Intervening precipitation was insufficient to modify the soil moisture below the second foot.

The winter precipitation has led to fairly high free-water contents in the upper 2 feet of the alfalfa field. Omitting these, the average free-water contents by successive 5-foot sections are 3.8, 3.7, and 5.0%, as compared with 3.2, 10.6, and 13.7% in the adjoining cultivated field. It is to be observed that the free-water is not as low in any foot in this alfalfa as in the preceding six-year-old field on upland. Due to receiving runoff water from higher ground, an alfalfa meadow situated as this one, might be expected to continue more productive than one located on upland.

### EFFECT OF CROPPING TO ALFALFA DURING THREE YEARS, 1925–27

Soil moisture determinations to a depth of 15 feet were made at the end of the 1927 season in an upland field of alfalfa (Fig. 1, C) sown three years previously. This field was originally a portion of the adjacent cultivated field (Fig. 1, A) described in connection with Table 1. Due to very dry weather, the alfalfa made a slow start and no yields were secured the first season. In 1926 and 1927 the yields were, respectively, 2.82 and 4.83 tons per acre.

TABLE 3.—*Comparative soil moisture contents to a depth of 15 feet in a field cropped to alfalfa during a three-year period ending in 1927 and in an adjacent cultivated field which had never been cropped to alfalfa.*

Sampled following the 1927 crop.

| Depth of sample in feet | Water content of soil* | | | | Deviation, Column 3 from Column 5 |
|---|---|---|---|---|---|
| | Alfalfa field | | Cultivated field | | |
| | Total % | Free % | Total % | Free % | % |
| (1) | (2) | (3) | (4) | (5) | (6) |
| 1 | 14.4 | 2.1 | 19.1 | 7.2 | —5.1 |
| 2 | 18.3 | 2.5 | 18.5 | 4.7 | —2.2 |
| 3 | 16.6 | 2.4 | 18.3 | 4.1 | —1.7 |
| 4 | 15.4 | 2.0 | 19.4 | 5.6 | —3.6 |
| 5 | 15.0 | 2.0 | 22.5 | 9.3 | —7.3 |
| 6 | 15.1 | 2.3 | 24.4 | 11.8 | —9.5 |
| 7 | 14.7 | 2.0 | 24.2 | 11.3 | —9.3 |
| 8 | 14.9 | 2.2 | 25.8 | 13.3 | —11.1 |
| 9 | 14.9 | 2.5 | 26.2 | 13.4 | —10.9 |
| 10 | 14.8 | 3.0 | 26.4 | 13.7 | —10.7 |
| 11 | 14.3 | 2.6 | 25.8 | 13.4 | —10.8 |
| 12 | 14.5 | 2.4 | 26.0 | 13.8 | —11.4 |
| 13 | 14.6 | 2.9 | 26.0 | 14.0 | —11.1 |
| 14 | 14.4 | 2.9 | 26.0 | 14.2 | —11.3 |
| 15 | 14.2 | 2.7 | 24.3 | 12.7 | —10.0 |
| | Averages of Successive 5-foot Depths | | | | |
| 1–5 | 15.9 | 2.2 | 19.6 | 6.2 | —4.0 |
| 6–10 | 14.9 | 2.4 | 25.4 | 12.7 | —10.3 |
| 11–15 | 14.4 | 2.7 | 25.6 | 13.6 | —10.9 |

*Moisture content of soil determined from an average of four cores in case of the alfalfa field and six cores for the cultivated field.

The moisture data for these fields are shown in Table 3. Three years after planting the free-water content to a depth of 15 feet in the alfalfa field averaged 2.4%. This is the same percentage as found for the corresponding depth in the six-year-old field, and averages 8.4% below that in the adjoining cultivated field never cropped to alfalfa. It is also significantly lower than that in the four-year-old field located on terrace land.

### EFFECT OF CROPPING TO ALFALFA DURING TWO YEARS, 1926–27

A field of alfalfa (Fig. 1, J) was sown in the fall of 1925 adjacent to a cultivated grain field (Fig. 1, K) which has never grown alfalfa. This young alfalfa meadow was merely clipped for weed control in its first season and no crop was harvested. In its second season, 1927, it yielded at the rate of 4.21 tons of hay per acre. At the end of that season the moisture content was determined for both fields to a depth of 25 feet. The data indicate (Table 4) that even two years of alfalfa may deplete the soil moisture far beyond the reach of ordinary cereal crops.

The alfalfa land contained an average of 4.4% free-water to a depth of 25 feet, while the cultivated field averaged 10.6% free-water to the same depth. As averages of successive 5-foot depths, the alfalfa meadow contained 2.7, 10.1, 8.7, 6.1, and 3.0% less free-water, respectively, than the cultivated field.

A marked reduction in free-water extended to the twenty-third foot with some indication that a little water had been drawn from the twenty-fifth foot. The average free-water content of 2.4% found in the three- and six-year-old upland fields to a depth of 15 feet has been approximately attained in this two-year-old field to a depth of 7 feet, while to a depth of 15 feet it was only 1.3% higher.

### REDUCED YIELDS ACCOMPANY DEPLETED SUBSOIL MOISTURE

The data in the accompanying tables indicate that alfalfa on upland soil, within a few years after sowing, may more or less completely deplete the subsoil of available moisture to depths exceeding 15 to 20 feet. Therefore, if alfalfa is to get further water from the subsoil, it must abstract it from a less available residuum or from greater depths by further extension of its root system. In both respects there are, undoubtedly, physiological limits. Therefore there must come a time in the life of alfalfa when the subsoil as a moisture reservoir must be considered as exhausted. Unless ground water exists close enough to the root zone to function through capillarity, yields must decline to a level established by seasonal rainfall.

TABLE 4.—*Comparative soil moisture contents to a depth of 25 feet in a field cropped to alfalfa during a two-year period ending in 1927 and in an adjacent cultivated field which had never been cropped to alfalfa.*

Sampled following the 1927 crop.

| Depth of sample in feet | Water content of soil* Alfalfa field Total % | Alfalfa field Free % | Cultivated field Total % | Cultivated field Free % | Deviation, Column 3 from Column 5 % |
|---|---|---|---|---|---|
| (1) | (2) | (3) | (4) | (5) | (6) |
| 1 | 12.7 | 1.6 | 20.2 | 9.1 | —7.5 |
| 2 | 15.1 | 1.2 | 18.1 | 4.2 | —3.0 |
| 3 | 16.9 | 3.0 | 16.8 | 2.9 | +0.1 |
| 4 | 17.0 | 3.5 | 16.2 | 2.7 | +0.8 |
| 5 | 15.5 | 2.4 | 19.5 | 6.4 | —4.0 |
| 6 | 15.5 | 2.9 | 24.3 | 11.7 | —8.8 |
| 7 | 15.4 | 3.1 | 25.4 | 13.1 | —10.0 |
| 8 | 16.7 | 4.2 | 26.2 | 13.7 | —9.5 |
| 9 | 16.2 | 3.4 | 26.7 | 13.9 | —10.5 |
| 10 | 16.0 | 3.9 | 27.7 | 15.6 | —11.7 |
| 11 | 16.9 | 4.8 | 25.4 | 13.3 | —8.5 |
| 12 | 16.2 | 4.0 | 25.7 | 13.5 | —9.5 |
| 13 | 18.1 | 5.9 | 26.2 | 14.0 | —8.1 |
| 14 | 18.7 | 6.8 | 26.0 | 14.9 | —8.1 |
| 15 | 16.6 | 5.3 | 25.8 | 14.5 | —9.2 |
| 16 | 15.5 | 4.3 | 23.5 | 12.3 | —8.0 |
| 17 | 16.9 | 5.7 | 22.8 | 11.6 | —5.9 |
| 18 | 16.3 | 5.1 | 22.0 | 10.8 | —5.7 |
| 19 | 15.3 | 4.6 | 21.0 | 10.3 | —5.7 |
| 20 | 15.4 | 4.3 | 20.6 | 9.5 | —5.2 |
| 21 | 17.2 | 4.9 | 22.7 | 10.4 | —5.5 |
| 22 | 17.9 | 5.9 | 21.8 | 9.8 | —3.9 |
| 23 | 17.7 | 5.6 | 21.0 | 8.9 | —3.3 |
| 24 | 19.5 | 7.6 | 20.7 | 8.8 | —1.2 |
| 25 | 19.3 | 7.2 | 20.1 | 8.0 | —0.8 |
| | | Averages of Successive 5-foot Depths | | | |
| 1–5 | 15.4 | 2.3 | 18.2 | 5.0 | —2.7 |
| 6–10 | 16.0 | 3.5 | 26.1 | 13.6 | —10.1 |
| 11–15 | 17.3 | 5.3 | 25.8 | 14.0 | —8.7 |
| 16–20 | 15.9 | 4.8 | 22.0 | 10.9 | —6.1 |
| 21–25 | 18.3 | 6.2 | 21.3 | 9.2 | —3.0 |

*Moisture content of soil determined in each case from a composite of two cores. Comparable 1-foot sections of soil from the two fields were composited for hygroscopic coefficient determinations.

The yields of alfalfa obtained on the three upland fields previously discussed in connection with Tables 1, 3, and 4, are shown in Table 5. For comparison, the yields of corn, oats, and winter wheat on neighboring comparable fields are also shown. The precipitation for each alfalfa year, September 1 to August 31, is also indicated in the table.

TABLE 5.—*Yields of three upland alfalfa fields and comparative yields of corn, oats, and winter wheat during five years, 1923–27.*

| | Yield per acre* | | | | | | | | | Seasonal |
|---|---|---|---|---|---|---|---|---|---|---|
| | Alfalfa fields† | | | Cultivated fields | | | | | | precipita- |
| Year | 1922–27 | 1925–27 | 1926–27 | Total production Corn | Oats | Wheat | Grain Corn | Oats | Wheat | tion, Sept. 1–Aug. 31 |
| | *Lbs.* | *Lbs.* | *Lbs.* | *Lbs.* | *Lbs.* | *Lbs.* | *Bu.* | *Bu.* | *Bu.* | *Inches* |
| 1923 | 9,520 | .... | .... | 5,370 | 3,380 | 2,810 | 43.6 | 50.4 | 18.6 | 28.1 |
| 1924 | 14,360 | .... | .... | 3,600 | 1,890 | 5,560 | 25.1 | 33.7 | 45.1 | 29.0 |
| 1925 | 9,800 | .... | .... | 5,100 | 1,270 | 1,410 | 21.5 | 19.3 | 10.0 | 23.9 |
| 1926 | 3,380 | 5,640 | .... | 1,730 | 950 | 1,810 | 2.5 | 7.1 | 11.3 | 19.3 |
| 1927 | 4,700 | 9,660 | 8,420 | 5,930 | 3,300 | 7,050 | 45.0 | 55.4 | 43.0 | 31.0 |
| Ave. | 8,352 | .... | .... | 4,346 | 2,158 | 3,728 | 27.5 | 33.2 | 25.6 | 26.3 |

*The alfalfa yields are for hay containing 15% moisture. The yields of corn, oats, and wheat were secured from adjacent fields and are based on field-cured material. The official U. S. Weather Bureau normal precipitation for Lincoln, Nebr., is 27.51 inches.

†Due to variability in alfalfa fields becoming established, yields are not reported for the first year.

As a five-year average, the alfalfa in the six-year-old field has yielded 8,352 pounds per acre or 1.9, 3.9, and 2.2 times the total yield of corn, oats, and wheat, respectively. In 1927 the yield was only 79% and 67% of that from corn and wheat, respectively.

The maximum yield in the six-year-old field was attained in its third year (1924). The yield of the fourth year was somewhat larger than during the second, even though the precipitation was considerably below normal. The fifth year, very much below normal in precipitation, the alfalfa yielded a minimum, although the yield was very good on a field sown the preceding season on land not previously cropped to alfalfa. In 1927, which was the wettest year of the five, the yield on the six-year-old field was again low, while yields on the newer fields were high.

In the six-year-old field 63% of the total alfalfa hay yield (4,700 pounds) for 1927 was produced in the first cutting which was harvested in June (Table 6). The next two cuttings comprised, respectively, 32 and 5% of the total. The normal rainfall at Lincoln from September 1 to April 30 is 11.40 inches. During this period of 1926 to 1927, 20.99 inches of precipitation occurred, or 9.50 inches in excess of normal. As a consequence, the upper soil was well supplied with water for production of the first cutting. As an average of the upper 6 feet of soil in the alfalfa field there was 7.8% more moisture in May (Table 7) than there was in August following.

TABLE 6.—*Comparative yields by cuttings of irrigated and non-irrigated six-year-old alfalfa, 1927.*

| Treatment* | Yield of hay in tons per acre with 15% moisture content | | | | |
|---|---|---|---|---|---|
| | Cutting | | | | Total for |
| | First | Second | Third | Fourth | season |
| (1) | (2) | (3) | (4) | (5) | (6) |
| Non-irrigated........ | 1.49 | 0.74 | 0.12 | 0 | 2.35 |
| Irrigated............ | 1.49 | 2.09 | 2.35 | 0.79 | 6.72 |

*Water was applied to the irrigated plat during the growth of the second, third, and fourth cuttings at an estimated rate of 12 inches per cutting. Without irrigation, this meadow yielded during consecutive years as follows: 1923, 4.76 tons; 1924, 7.18 tons; 1925, 4.9 tons; 1926, 1.69 tons; and 1927, 2.35 tons per acre.

TABLE 7.—*Comparative soil moisture contents in irrigated and non-irrigated alfalfa fields during the summer of 1927.*

| Depth of sample in feet | Moisture content of soil* | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Non-irrigated alfalfa | | | | | | Irrigated alfalfa | | |
| | March | May | June | July | August | October | July | August | October |
| | % | % | % | % | % | % | % | % | % |
| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) |
| 1 | 31.7 | 25.7 | 20.0 | 20.3 | 15.3 | 14.2 | 29.4 | 27.7 | 24.5 |
| 2 | 26.8 | 25.6 | 21.2 | 17.4 | 17.2 | 16.4 | 27.8 | 27.1 | 26.0 |
| 3 | 21.2 | 24.0 | 18.2 | 15.3 | 15.7 | 16.3 | 23.6 | 24.2 | 23.6 |
| 4 | 16.3 | 25.2 | 18.4 | 15.6 | 14.9 | 14.0 | 24.7 | 25.1 | 23.8 |
| 5 | 14.3 | 21.4 | 16.7 | 14.6 | 14.0 | 13.3 | 24.3 | 26.1 | 25.4 |
| 6 | 15.4 | 15.9 | 14.7 | 14.7 | 14.3 | 12.0 | 15.3 | 24.8 | 24.9 |
| 7 | ... | ... | ... | ... | 13.8 | 13.2 | ... | 25.3 | 23.2 |
| 8 | ... | ... | ... | ... | 13.7 | 13.5 | ... | 21.4 | 18.9 |
| 9 | ... | ... | ... | ... | 13.8 | 14.1 | ... | 18.4 | 16.7 |
| 10 | ... | ... | ... | ... | 13.5 | 13.8 | ... | 14.6 | 15.0 |

*Moisture content of soil determined from a composite of three cores in each case. Soil samples were taken in June, July, August, and October following each cutting of alfalfa. Water was applied to the irrigated plat during the growth of the second, third, and fourth cuttings.

## MEADOWS WITH DEPLETED SUBSOIL MOISTURE RESPOND TO IRRIGATION

Additional evidence of the seriousness of depletion of subsoil moisture in the six-year-old field was obtained through some irrigation experiments. Following the removal of the first cutting in 1927, water was applied on a small representative area at various times during the growth of the second, third, and fourth cuttings. The irrigation was done during the night at three different times during the growth of each cutting by means of an overhead sprinkler. No exact measurement was made of the amount, but it was estimated that approximately 4 inches of water were added during each application, or a total of 36 inches in all. The yields of hay secured from the irrigated and non-irrigated areas are reported in Table 6. Subsoil

moisture contents to depths of 6 and 10 feet following each cutting are reported in Table 7, together with moisture contents in the unirrigated land.

Including the first cutting which was not irrigated, the yields for the season were 2.35 tons per acre for the non-irrigated and 6.72 tons for the irrigated alfalfa. Following the date of applying the first water, the yields for non-irrigated and irrigated alfalfa were 0.86 and 5.23 tons per acre, respectively. The second and third cuttings of the non-irrigated alfalfa yielded only 35% and 5% as much, respectively, as the same cuttings with irrigation. The irrigation increased the fourth cutting from a complete failure to 0.79 ton.

The soil samples taken after each cutting to a depth of 6 to 10 feet indicate that there was very little available moisture in the non-irrigated area, whereas in the irrigated soil the upper 5 feet contained an average of 26.0% moisture in July after the removal of the second cutting. By August moisture had penetrated into the ninth foot.

The heavy yield of the first cutting following the unusually high precipitation and the greatly increased yield following surface irrigation are evidence that the marked reduction in yield of this meadow the past three years has been due to depleted soil moisture.

## CALCULATIONS OF MOISTURE DEPLETION BASED ON WATER REQUIREMENT

Another method of arriving at the rate at which alfalfa depletes the subsoil of moisture is based on computations from accepted water requirement ratios. It is a well-established fact that alfalfa requires more water per unit of dry matter produced than any other commonly grown field crop. Kiesselbach and Anderson (5) reported a water requirement ratio of 858 for alfalfa during 1916, which is 3.2, 2.1, and 2.7 times that found for corn, oats, and wheat, respectively. Shantz and Piemeisel (8) reported that as an average for seven years, alfalfa had a water requirement ratio of $859 \pm 10$ which was 2.4, 1.4, and 1.8 times that of corn, oats, and wheat. Richardson (6) found the average transpiration ratio during a four-year period to be 380 for wheat, 390 for oats, and 790 for alfalfa. During this period the three cuttings of alfalfa harvested in spring and early summer had a water requirement of 597 compared with 1,085 for three cuttings harvested during summer and early autumn.

Using the figure 858 and reducing the yields of the six-year-old field shown in Table 5 to a moisture-free basis, the water requirements in inches of rainfall for the five successive years are 30.6, 46.2,

31.5, 10.9, and 15.1 inches.[6] The average, 26.8 inches, exceeds the average precipitation during these years by 0.5 inch. The amount of water removed from the subsoil, as calculated from data in Table 1, is equivalent to a total of 32.9 inches, or an average of 6.6 inches per year.[7] Subtracting this figure from 26.8 above, gives 20.2 inches as that portion of the 26.8 inches of precipitation which has been utilized by the crop. Water amounting to 6.1 inches, or 23% of the annual precipitation, was apparently lost by runoff and surface evaporation. This is not an extreme figure for such loss.

A large portion of the 32.9 inches of subsoil water must have been removed during the early years when water requirement exceeded precipitation. The fact that in the last two years the precipitation considerably exceeded the water requirement must be taken as evidence that the subsoil had become largely exhausted. It seems evident that in succeeding years the yields on this field will be almost entirely dependent on seasonal rainfall.

## RESTORATION OF SUBSOIL MOISTURE FOLLOWING ALFALFA

It has been shown in the foregoing tests that a six-year-old alfalfa meadow under eastern Nebraska upland conditions will reduce the soil moisture for a depth of 25 feet to within 2 or 3% of the hygroscopic coefficient. Even three years of alfalfa may reduce the moisture content to the same extent for a depth of 10 feet or more below the feeding range of ordinary cereal crops. Such subsoil moisture depletion is not to be looked upon as harmful to succeeding cereal crops, since as Burr (4) and others have shown, very little moisture is ever elevated by capillarity from regions beyond the root zone. On the other hand, as has been pointed out by Kiesselbach and Anderson (5), alfalfa may be expected to produce comparatively low yields on such land if resown before the subsoil moisture has been restored.

## EFFECT OF 15 YEARS OF GRAIN CROPPING UPON SUBSOIL MOISTURE RESTORATION

A cultivated upland field (Fig. 1, E) that was plowed up from an old stand of alfalfa in 1912 has provided opportunity for studying the degree of moisture restoration during 15 years of cropping to a rota-

[6]It is recognized that transpiration is dependent in a large measure on environmental conditions and these calculations therefore should be considered as being suggestive rather than absolute.

[7]Six per cent of soil moisture per foot is considered as equivalent to 1 inch of water. This is based on actual volume-weight determinations to a depth of 10 feet.

tion of corn, oats, and winter wheat. This field was sampled to a depth of 35 feet in 1927. The moisture content at the time it was broken from alfalfa is not known, but it may be assumed that it was fairly similar to that found in existing old alfalfa fields today. The moisture data are therefore compared with those of the six-year-old alfalfa field (Fig. 1, B) discussed earlier. In addition, comparison is made with a cultivated field (Fig. 1, A) never cropped to alfalfa. The data are shown in Table 8 and Fig. 3.

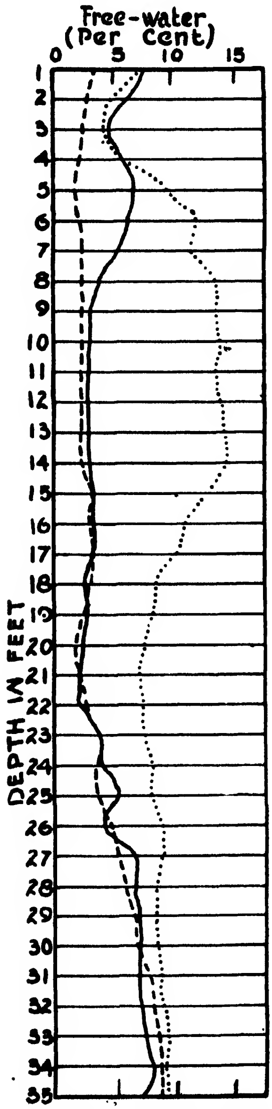


FIG. 3.—Restoration of subsoil moisture. Comparative free-water content in 1927 at 1-foot intervals to a depth of 35 feet in a field plowed up from alfalfa in 1912 and subsequently cropped to corn, oats and winter wheat for 15 years (———), a field cropped to alfalfa during 1922-27 (- - - -), and an adjacent cultivated field which has never been cropped to alfalfa (· · · ·).

Although the deviations in the free-water content of the field in alfalfa 15 years ago from the field now in alfalfa are positive on the average to a depth of 30 feet, there is no clear evidence that any significant storage has extended below 7 feet. The deviations below the seventh foot are all within experimental error in sampling and determining free-water content. The average change during 15 years in free-water content below 15 feet has been 0.0%. The average below 5 feet is 0.4% increase. At this rate it appears that it would require 225 years to restore the subsoil moisture between 5 and 35 feet to the average of 10.0% carried by Field A that has never grown alfalfa.

When averaged by 5-foot sections the decreasing positive deviations followed by negative values at 30 and 35 feet may be taken as indicative that capillarity has had no apparent effect in elevating moisture from the water table at a depth of 100 feet.

TABLE 8.—*Comparative soil moisture contents to a depth of 35 feet in a grain field broken up from six-year-old alfalfa in 1912, in a field cropped to alfalfa during a six-year period ending in 1927, and in a field similarly cropped except that it has never grown alfalfa.*

Sampled following the 1927 crop.

| Depth of sample in feet | Water content of soil*: Cultivated field previously in alfalfa during 1907–12, Total % | Free % | Alfalfa field during 1922–27, Free % | Cultivated field never in alfalfa, Free % | Deviation, Column 3 from Column 4 % | Column 5 % |
|---|---|---|---|---|---|---|
| (1) | (2) | (3) | (4) | (5) | (6) | (7) |
| 1 | 21.7 | 7.7 | 3.4 | 7.2 | +4.3 | +0.5 |
| 2 | 21.5 | 6.1 | 2.8 | 4.7 | +3.3 | +1.4 |
| 3 | 18.4 | 4.6 | 2.4 | 4.1 | +2.2 | +0.5 |
| 4 | 19.2 | 5.7 | 2.2 | 5.6 | +3.4 | +0.1 |
| 5 | 19.7 | 6.7 | 1.6 | 9.3 | +5.1 | —2.6 |
| 6 | 18.8 | 6.1 | 2.0 | 11.8 | +4.0 | —5.7 |
| 7 | 18.2 | 5.4 | 2.4 | 11.3 | +3.0 | —5.9 |
| 8 | 16.6 | 3.6 | 2.4 | 13.3 | +1.2 | —9.7 |
| 9 | 15.6 | 3.1 | 2.4 | 13.4 | +0.7 | —10.3 |
| 10 | 15.4 | 3.3 | 2.3 | 13.7 | +1.0 | —10.4 |
| 11 | 14.6 | 3.0 | 2.1 | 13.4 | +0.9 | —10.4 |
| 12 | 14.0 | 2.7 | 2.2 | 13.8 | +0.5 | —11.1 |
| 13 | 14.0 | 2.8 | 2.3 | 14.0 | +0.5 | —11.2 |
| 14 | 14.3 | 3.0 | 2.2 | 14.2 | +0.8 | —11.2 |
| 15 | 14.2 | 3.2 | 3.0 | 12.7 | +0.2 | —9.5 |
| 16 | 13.4 | 3.1 | 2.9 | 10.8 | +0.2 | —7.7 |
| 17 | 13.1 | 3.2 | 3.0 | 10.3 | +0.2 | —7.1 |
| 18 | 14.0 | 2.5 | 2.8 | 8.3 | —0.3 | —5.8 |
| 19 | 14.4 | 2.5 | 2.4 | 8.0 | +0.1 | —5.5 |
| 20 | 13.9 | 2.3 | 1.6 | 7.3 | +0.7 | —5.0 |
| 21 | 13.3 | 2.1 | 2.0 | 6.7 | +0.1 | —4.6 |
| 22 | 13.3 | 2.4 | 2.6 | 7.2 | —0.2 | —4.8 |
| 23 | 13.5 | 3.6 | 3.7 | 7.2 | —0.1 | —3.6 |
| 24 | 14.3 | 3.9 | 3.4 | 7.7 | +0.5 | —3.8 |
| 25 | 15.5 | 5.2 | 3.4 | 7.8 | +1.8 | —2.6 |
| 26 | 14.7 | 4.0 | 4.5 | 8.7 | —0.5 | —4.7 |
| 27 | 17.1 | 6.6 | 5.2 | 8.9 | +1.1 | —2.3 |
| 28 | 16.6 | 6.4 | 5.7 | 8.1 | +0.7 | —1.7 |
| 29 | 17.0 | 6.6 | 6.4 | 8.2 | +0.2 | —1.6 |
| 30 | 17.7 | 6.9 | 6.5 | 8.3 | +0.4 | —1.4 |
| 31 | 17.4 | 6.9 | 7.6 | 8.5 | —0.7 | —1.6 |
| 32 | 17.8 | 7.0 | 7.9 | 8.6 | —0.9 | —1.6 |
| 33 | 18.8 | 7.3 | 8.4 | 9.1 | —1.1 | —1.8 |
| 34 | 19.0 | 7.8 | 8.5 | 8.9 | —0.7 | —1.1 |
| 35 | 17.8 | 6.9 | 8.5 | 9.3 | —1.6 | —2.4 |

TABLE 8.—*Concluded.*

Averages of Successive 5-foot Depths

| | | | | | | |
|---|---|---|---|---|---|---|
| 1–5 | 20.1 | 6.2 | 2.5 | 6.2 | +3.7 | 0 |
| 6–10 | 16.9 | 4.3 | 2.3 | 12.7 | +2.0 | —8.4 |
| 11–15 | 14.2 | 2.9 | 2.3 | 13.6 | +0.6 | —10.7 |
| 16–20 | 13.8 | 2.7 | 2.5 | 8.9 | +0.2 | —6.2 |
| 21–25 | 14.0 | 3.4 | 3.0 | 7.3 | +0.4 | —3.9 |
| 26–30 | 16.6 | 6.1 | 5.7 | 8.4 | +0.4 | —2.3 |
| 31–35 | 18.2 | 7.2 | 8.2 | 8.9 | —1.0 | —1.7 |

*Moisture content of soil determined from an average of two and three cores in case of the alfalfa and six cores for the cultivated field.

## EFFECT OF THREE YEARS OF GRAIN CROPPING UPON SUBSOIL MOISTURE RESTORATION

### UPLAND

More direct evidence of the slowness of restoration of subsoil moisture under upland conditions has been obtained on another field (Fig. 1, G) which was sampled in the spring of 1925 when alfalfa on

TABLE 9.—*Comparative free-water contents determined to a depth of 15 feet at the time of breaking up a four-year-old stand of alfalfa in the spring of 1925 and again in 1927 after it had borne a crop each of corn, oats, and winter wheat.*

This field had previously been in alfalfa for a six-year period ending in 1912.

| Depth of sample in feet | Water content of soil* 1925 Total | 1925 Free | 1927 Total | 1927 Free | Deviation, Column 5 from Column 3 |
|---|---|---|---|---|---|
| | % | % | % | % | % |
| (1) | (2) | (3) | (4) | (5) | (6) |
| 1 | 27.9 | 17.1 | 20.4 | 9.6 | —7.5 |
| 2 | 20.9 | 6.5 | 19.7 | 5.3 | —1.2 |
| 3 | 15.3 | 1.1 | 15.7 | 1.5 | +0.4 |
| 4 | 14.1 | 0.6 | 14.9 | 1.4 | +0.8 |
| 5 | 14.5 | 1.3 | 15.1 | 1.9 | +0.6 |
| 6 | 14.2 | 1.3 | 14.8 | 1.9 | +0.6 |
| 7 | 14.1 | 1.6 | 14.3 | 1.8 | +0.2 |
| 8 | 14.3 | 1.9 | 14.4 | 2.0 | +0.1 |
| 9 | 14.6 | 2.1 | 14.5 | 2.0 | —0.1 |
| 10 | 14.3 | 1.9 | 14.7 | 2.3 | +0.4 |
| 11 | 14.5 | 2.3 | 14.4 | 2.2 | —0.1 |
| 12 | 14.5 | 2.4 | 14.1 | 2.0 | —0.4 |
| 13 | 14.0 | 2.0 | 14.1 | 2.1 | +0.1 |
| 14 | 14.1 | 2.6 | 14.2 | 2.7 | +0.1 |
| 15 | 13.7 | 2.4 | 13.3 | 2.0 | —0.4 |
| Averages of Successive 5-foot Depths | | | | | |
| 1–5 | 18.5 | 5.3 | 17.2 | 3.9 | —1.4 |
| 6–10 | 14.3 | 1.8 | 14.5 | 2.0 | +0.2 |
| 11–15 | 14.2 | 2.3 | 14.0 | 2.2 | —0.1 |

*Moisture content of soil determined from an average of 12 cores.

that field was broken up, and later sampled in the fall of 1927 after it had grown a crop each of corn, oats, and wheat. The data, shown in Table 9, are based on composites of 12 cores, the samples being taken the second time within 5 feet of where they were taken first.

As averages for successive 5-foot depths, the changes in free-water content during the three-year period are —1.4, +0.2, and —0.1%.

TABLE 10.—*Comparative free-water contents determined to a depth of 15 feet in a low-lying field at the time of breaking up from a four-year-old stand of alfalfa in the spring of 1925 and again in 1927 after it had borne a crop each of corn, oats, and winter wheat.*

| Depth of sample in feet | Water content of soil* | | | | Deviation, Column 5 from Column 3 |
|---|---|---|---|---|---|
| | 1925 | | 1927 | | |
| | Total % | Free % | Total % | Free % | % |
| (1) | (2) | (3) | (4) | (5) | (6) |
| 1 | 29.3 | 20.4 | 20.5 | 11.6 | —8.8 |
| 2 | 21.1 | 10.7 | 15.3 | 4.9 | —5.8 |
| 3 | 17.0 | 3.9 | 18.3 | 5.2 | +1.3 |
| 4 | 18.0 | 4.1 | 18.5 | 4.6 | +0.5 |
| 5 | 17.1 | 3.3 | 20.0 | 6.2 | +2.9 |
| 6 | 16.9 | 3.4 | 21.9 | 8.4 | +5.0 |
| 7 | 16.1 | 3.4 | 20.7 | 8.0 | +4.6 |
| 8 | 16.5 | 3.7 | 21.3 | 8.5 | +4.8 |
| 9 | 16.5 | 4.0 | 20.1 | 7.6 | +3.6 |
| 10 | 17.0 | 4.2 | 19.6 | 6.8 | +2.6 |
| 11 | 17.6 | 4.9 | 18.3 | 5.6 | +0.7 |
| 12 | 17.8 | 5.1 | 17.9 | 5.2 | +0.1 |
| 13 | 17.2 | 5.1 | 17.3 | 5.2 | +0.1 |
| 14 | 16.7 | 4.9 | 17.3 | 5.5 | +0.6 |
| 15 | 17.1 | 4.9 | 17.3 | 5.1 | +0.2 |
| | Averages of Successive 5-foot Depths | | | | |
| 1–5 | 20.5 | 8.5 | 18.5 | 6.5 | —2.0 |
| 6–10 | 16.6 | 3.7 | 20.7 | 7.8 | +4.1 |
| 11–15 | 17.3 | 5.0 | 17.6 | 5.3 | +0.3 |

*Moisture content of soil determined from an average of four cores.

### LOWLAND

Field I (Fig. 1) which is located on the terrace and which is a continuation of the upland Feld G, as far as cropping to alfalfa and other crops since 1921 is concerned, was also sampled in 1925 and again in 1927. The data shown in Table 10 indicate the importance of topography and runoff-water supply on restoration of subsoil water. In this field considerably more water has been stored than in the upland field. Below the upper 5 feet which are subject to seasonal variation, significant increases in free-water are shown as deep as 10 feet. The average increase between 6 and 10 feet is 4.1%.

It is apparent from these data that there is much more prospect of re-cropping low-lying land to alfalfa than upland where loss of water by runoff is probable. In addition, such low-lying meadows may be expected to continue productive for a longer period, due to the water received from higher ground.

It should be observed (Table 5) that the average precipitation during the last three years has been subnormal which may account in part for the very low degree of storage indicated in Tables 9 and 10. As for the 15-year period covered by the data in Table 8, the precipitation has been only 0.8 inch below normal. In one of the years (1914) the rainfall was 40.0 inches.

## ALFALFA PRODUCTION ON LAND PREVIOUSLY IN ALFALFA

### YIELDS OF ALFALFA SOWN IN 1921

Alfalfa was sown in Field G (Fig. 1) in the fall of 1920 on land that had previously been cropped to alfalfa for a period of years ending in 1912. During the intervening period a rotation of corn, oats, and wheat had been followed. A splendid stand of alfalfa was secured that persisted throughout the succeeding years. The yields of forage, however, have been strikingly low and reflect a very limited supply of subsoil moisture. (See Table 9.) The growth consisted largely of annual grasses in 1921 and no yields were determined that year. In 1922, 1923, and 1924 the respective yields in this meadow were only 1.15 tons, 2.56 tons, and 2.50 tons compared with 2.59, 4.26, and 4.40 tons per acre on adjacent land (Fig. 1, D) that had not previously grown alfalfa. As an average for the three years, the second-term alfalfa suffered a reduction in yield of 45% due to previous depletion of subsoil moisture.

### YIELDS OF ALFALFA SOWN IN 1925

Similar results were secured from a corresponding alfalfa meadow, (Fig. 1, F) sown in the fall of 1924. A period of 12 years had elapsed since the breaking up of well-established alfalfa on the same land in 1912. Although a satisfactory stand was secured and has persisted since, the yields of forage have been unsatisfactorily low as a result of subsoil moisture shortage. The meadow was merely clipped in 1925 without yield determination. In 1926 and 1927 the respective yields of hay were 0.93 and 1.78 tons per acre. Aside from the first cutting in 1927 which was favored by unusually heavy precipitation during the previous fall and early spring and which yielded 0.97 ton per acre, the growth at all times has been very short and stunted. This was in

striking contrast with alfalfa sown at the same time on adjoining land (Field C) not previously in alfalfa, the yield being 2.82 tons and 4.83 tons per acre in 1926 and 1927, respectively. As an average for the two years, the second-term alfalfa yielded only 35% as much as the other meadow.

In this field moisture samples were taken to a depth of 15 feet at the time of sowing the alfalfa and again after three years of cropping

TABLE 11.—*Comparative free-water contents determined to a depth of 15 feet in an alfalfa field at the time of sowing in the fall of 1924 and again in 19?7 after three years of cropping to alfalfa.*

This field had previously been in alfalfa for a six-year period ending in 1912.

| Depth of sample in feet | Water content of soil* | | | | Deviation, Column 5 from Column 3 |
|---|---|---|---|---|---|
| | 1924 | | 1927 | | |
| | Total | Free | Total | Free | |
| | % | % | % | % | % |
| (1) | (2) | (3) | (4) | (5) | (6) |
| 1 | 23.1 | 11.4 | 14.3 | 2.6 | —8.8 |
| 2 | 20.0 | 5.5 | 16.5 | 2.0 | —3.5 |
| 3 | 15.8 | 1.7 | 15.1 | 1.0 | —0.7. |
| 4 | 15.0 | 1.7 | 14.4 | 1.1 | —0.6 |
| 5 | 15.5 | 2.4 | 14.1 | 1.0 | —1.4 |
| 6 | 15.7 | 2.9 | 14.3 | 1.5 | —1.4 |
| 7 | 15.9 | 3.2 | 14.2 | 1.5 | —1.7 |
| 8 | 15.6 | 3.2 | 14.0 | 1.6 | —1.6 |
| 9 | 14.9 | 2.3 | 14.1 | 1.5 | —0.8 |
| 10 | 14.7 | 2.4 | 14.2 | 1.9 | —0.5 |
| 11 | 14.3 | 2.0 | 14.1 | 1.8 | —0.2 |
| 12 | 13.8 | 1.9 | 13.8 | 1.9 | 0.0 |
| 13 | 13.8 | 2.3 | 13.7 | 2.2 | —0.1 |
| 14 | 13.5 | 2.3 | 13.6 | 2.4 | +0.1 |
| 15 | 13.8 | 2.8 | 13.8 | 2.8 | 0.0 |
| | Averages of Successive 5-foot Depths | | | | |
| 1–5 | 17.9 | 4.5 | 14.9 | 1.5 | —3.0 |
| 6–10 | 15.4 | 2.8 | 14.2 | 1.6 | —1.2 |
| 11–15 | 13.8 | 2.3 | 13.8 | 2.2 | —0.1 |

*Moisture content of soil determined from an average of 12 cores.

(Table 11). The residual effects of the alfalfa 12 years previous were very pronounced at the initial sampling. An averge of only 2.6% of water above the hygroscopic coefficient remained in the soil between the sixth and fifteenth foot.

The sampling three years later shows that very little additional moisture was removed from the subsoil of this field by the subsequent cropping of alfalfa. The sixth to fifteenth foot showed an average reduction of 0.7% moisture. The average free-water content of the

lower 10 feet is 1.9%. The presence of live roots throughout this depth, as shown by excavation, and their failure to lower the moisture to a greater degree leads to the conclusion that the point of non-availability had been reached.

## COMPARATIVE ALFALFA ROOT DEVELOPMENT IN MOIST AND DRY SUBSOILS

Excavations were made in the spring of 1928 for the purpose of comparing the root development in a vigorous, productive three-year-old meadow (Fig. 1, C) in alfalfa for the first time with that obtaining in an adjacent unproductive three-year-old meadow (Fig. 1, F) planted at the same time on land that had been previously cropped to alfalfa. Since 1912 the land occupied by these meadows has been cropped as one field. Seedbed preparation, sowing, and all conditions for growth, except subsoil moisture, have been identical.

At the time of sowing, the alfalfa in Field C had the advantage of an abundant subsoil moisture (Table 3), whereas the available moisture had been practically exhausted in Field F (Table 11). Root observations were made by means of trenches dug 10 feet deep in Field C and 14 feet deep in Field F. A corresponding 10-foot trench was dug in the adjoining Field A, which has never grown alfalfa, for comparison with the others as to characteristics of soil constitution.

### EFFECTS OF ALFALFA UPON SOIL CONSTITUTION

The drying out effects of cropping to alfalfa were very apparent in the constitution of the subsoil to the depth under observation. This subsoil is very heavy textured and its coefficient of shrinkage is fairly high. In the absence of alfalfa the subsoil below the sixth foot was free of cracks and crevices. Where alfalfa was growing the shrinkage produced by removal of water had produced innumerable vertical fissures in the subsoil, some at 10 to 14 feet being as much as 1 inch wide. The cracking was somewhat less marked in the field growing alfalfa for the first time. At the time of observation the subsoil from the sixth to tenth foot in the three fields A, F, and C contained an average of 12.7, 2.4, and 1.6% of free-water, respectively.

Under all conditions the subsoil was literally filled with the distinct. root markings and channels of former vegetation typical of this soil. The evidence of former root growth was more marked in Field F, thereby suggesting that at least a part of these markings were due to former alfalfa roots. Many of the roots of the present crop of alfalfa were traced through these old root channels. The discolored remains of roots from the alfalfa plowed up in 1912 were

found at a depth of 14 feet. At a depth of 8 feet the maximum diameter of these old roots was approximately 4 mm and at 14 feet approximately 3 mm.

## COMPARATIVE ROOT DEVELOPMENT

Although the excavations were not sufficiently deep to determine the maximum depth of penetration of the alfalfa roots in either case, very marked differences in root development were noted. In Field C, cropped to alfalfa for the first time, the average diameter of the roots was 7.7 mm at the surface and 1.8 mm in the fifth foot. Many roots at the latter depth were 2 to 3 mm in diameter. One root measured 2.5 mm in the eighth foot. Small fibrous roots were uniformly distributed throughout the soil without regard to the fissures that had begun to form.

In Field F the roots averaged only 4.6 mm in diameter at the surface and 0.2 mm in the fifth foot. The latter diameter is one-ninth that observed in the other meadow at the corresponding depth. Only one root was found with a diameter as great as 1 mm in the fifth foot.

In the region of the fifth foot the fine tap roots branched profusely within the vertical cracks into a network of very fine roots, clinging to every fissure face. They became less numerous with depth, but many were found in the fourteenth foot. Presumably the fissures, open below 5 or 6 feet as they must have been since 1912, had been the seat of some slight downward percolation or distillation of water and the roots had followed as a consequence of the slight amount of available moisture in the fissure faces. Practically none of the rootlets could be found within the soil mass itself.

Evidence of dead roots was observed at all levels in both fields. Undoubtedly in the natural competition between plants, the slower growing individuals have their roots confined to the drier levels and succumb from a lack of moisture induced by the plants of more aggressive growth. In these fields there has been very little evidence of loss of plants through direct winterkilling or disease.

In order to determine whether these roots were still functioning, small holes were bored horizontally 3 feet back into the sides of the excavation at the 14-foot depth, to facilitate lateral movement of water, and approximately 50 barrels of water were gradually added. Not to exceed 2 feet of standing water was maintained in the trench at a time, therefore any rise of moisture above the twelfth foot must have been by capillarity or root action. The trench was then refilled with soil after the water had seeped away. One end of the trench had

been dug only 10 feet deep. The alfalfa about the lower end which received the water grew much more vigorously, which is considered as evidence that the roots were alive and had absorbed the water at a depth of 10 feet or more and had lifted it through an equal distance of soil essentially void of available moisture.

## GENERAL APPLICATIONS

The results of these tests should be applicable over an extensive territory wherever reasonably similar soil and climatic conditions prevail. These conditions are characterized by a productive upland soil with a deep silty subsoil that is naturally well supplied with available moisture and capable of high water retention. The precipitation is largely of the torrential type and comes mainly during the growing season. The effective rainfall is usually insufficient in itself for a very high yield of alfalfa, and ordinarily is not in excess of the current needs of cereal crops. It is recognized that there are conditions where subsoil moisture does not have such unique significance in alfalfa production and the yields may continue indefinitely at a more uniform level.

With respect to the most effective use of subsoil moisture under the conditions of these tests, it would seem unwise to break up alfalfa before the period of high forage yields has passed. A continuation of the meadow thereafter would serve to lower the average yield. As a general practice it would be better to shift the alfalfa to a new field where the subsoil moisture supply is yet intact and relatively large yields are practically assured. Used in this way the alfalfa not only returns the maximum forage yields, but also serves to good advantage in soil improvement.

From the standpoint of a favorable moisture supply for succeeding cereal crops, little is to be gained by shortening the period in alfalfa. Whether it be long or short, the subsoil moisture supply becomes exhausted to depths far beyond the root penetration of the cereals.

Although it has been found no more difficult to secure a satisfactory stand of alfalfa on upland soil previously in this crop than on land never having grown it, the practice of sowing on such land is not to be recommended where other desirable fields are available. Invariably upland soils that are not irrigated will for years to come be deficient in subsoil moisture for a highly productive cropping to alfalfa the second time.

Re-establishment of a productive meadow is most feasible where surface irrigation may be practiced and may also often succeed on low-lying ground without irrigation. Under sub-irrigation conditions

a productive alfalfa meadow may also be re-established provided the roots succeed in reaching the ground water.

It would seem a valuable practice for farmers to keep a record of the location of previous alfalfa meadows. This would facilitate the avoidance of unintentional re-sowing on land the second time under conditions where this leads to disappointment.

More extensive data bearing on the cultural practices which may be followed in the restoration of subsoil moisture are much needed. The feasibility of summer fallow is debatable. A single season of such fallow cannot be expected to add greatly to the deep-seated subsoil moisture supply, and successive fallowing during a period of years would seem impractical.

The question of whether alfalfa should be grown at all on land where subsoil moisture has been depleted is mainly one involving the comparative value of alfalfa and other forage crops from the standpoint of their yield and utilization as feeds and their effect on soil fertility. The comparative value of alfalfa and of red clover, alsike clover, sweet clover, and other forage crops should be established for these depleted subsoil moisture conditions.

## SUMMARY

1. The productivity of alfalfa meadows occupying the land for the first time on the Nebraska Agricultural Experiment Station farm at Lincoln has declined rather abruptly about four to five years after sowing, even though a good healthy stand remains. This has been found to be due primarily to depletion of the available subsoil moisture. Such results are regarded as rather typical of most uplands in eastern Nebraska and similar territory where the annual precipitation is not supplemented by either surface- or sub-irrigation. The natural restoration of the subsoil moisture supply is at so slow a rate under usual cropping conditions that far smaller yields may be expected from a second cropping to alfalfa than from the first.

2. The point of non-availability of moisture in these alfalfa meadows appears to be approximately 2% above the hygroscopic coefficient.

3. Alfalfa drew upon the subsoil moisture supply to a depth of 33 feet in a six-year-old meadow and 25 feet in a two-year-old meadow. At the end of six-, three-, and two-year periods of growth in three upland meadows the free-water content had been reduced to approximately 2.5% to depths of 25, 15, and 7 feet, respectively. The average moisture content between the fifth and fifteenth foot

in the six-, three-, and two-year-old meadows has been reduced 11.0, 10.6, and 9.4%, respectively, below that in adjoining cultivated fields.

4. A six-year-old alfalfa meadow reached its peak of production in the third year, with 7.2 tons of cured forage per acre. Yields thereafter were curtailed by subsoil moisture depletion. The yields during the fifth and sixth years averaged only 2.0 tons per acre, even though a good healthy stand persisted. During the second to sixth years the forage yield of this alfalfa meadow was about twice the total yield of adjacent corn and wheat fields, whereas in the sixth year its yield was only 79 and 67% as large, respectively, as that of these two cereal crops.

5. Irrigation of a portion of this meadow in its sixth year increased the yield nearly three-fold, bringing it up to 6.72 tons for the season compared with 2.35 tons without irrigation. This is evidence that the shortage of production was due to moisture deficiency.

6. Because of its excessive water requirement ratio, alfalfa cannot be expected to be as productive as the common cereal crops after subsoil moisture has been exhausted and it has become reduced to dependence upon the annual rainfall. Computations based on a water requirement ratio of 858 indicate that approximately 27 acre inches of water were required annually to supply the transpiration needs of an alfalfa meadow during its second to sixth years. This is slightly in excess of the average annual precipitation during the period. During the second to fourth years water requirement considerably exceeded precipitation. This extra requirement was met by the moisture of the subsoil which appears to have lost during the six-year period a total of 32.9 inches. To maintain the high yield attained in the third year (12,206 pounds of moisture-free hay) would require 46 inches of transpirational water per year.

7. Under ordinary cropping conditions the natural restoration of subsoil moisture following alfalfa appears to be very slow. During 15 years of cropping to cereal crops following the breaking up of an established upland alfalfa meadow, very little moisture had accumulated beyond the seventh foot. The average increase in moisture content from the fifth to the thirty-fifth foot appears to have been 0.4%. At this rate approximately 225 years would be required to restore the subsoil moisture removed by six years of cropping to alfalfa. Subsoil moisture was replenished more rapidly on low-lying land that received runoff from higher ground.

8. Alfalfa is greatly handicapped on land that has at some time previously grown this crop. In one series of tests a meadow sown

eight years after the previous alfalfa was broken up yielded as a three-year average only 55% as much as a corresponding adjacent meadow that had not previously grown alfalfa. In a similar test started four years later the average yield for two years was only 35% as much. The average yield of the five crops of alfalfa grown in the absence of subsoil moisture was 1.78 tons per acre. Moisture tests showed that these results were due to deficiency of available subsoil moisture at time of planting.

9. Root studies in a three-year old alfalfa field on land that had once before grown alfalfa showed undersized tap roots that branched profusely at a depth of about 5 feet into a network of fine roots clinging to the faces of the many fissures which characterized the deep dry subsoil. These roots were traced to a depth of 14 feet. In a corresponding field that had not previously grown alfalfa the plants possessed characteristic long, sturdy tap roots, with many fine roots throughout the soil mass.

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# RECENT TRENDS IN FERTILIZER CONSUMPTION IN EUROPE[1]

H. R. SMALLEY[2]

In presenting this topic an attempt is made to compare in a general way the use of fertilizer just prior to the world war with its use in the latest years for which figures are available. In making these comparisons consumption statistics have been used for 1913 or 1914, as compared with those for 1925, 1926, or 1927. The exact period in every case is given in the footnotes following Table 1. Between

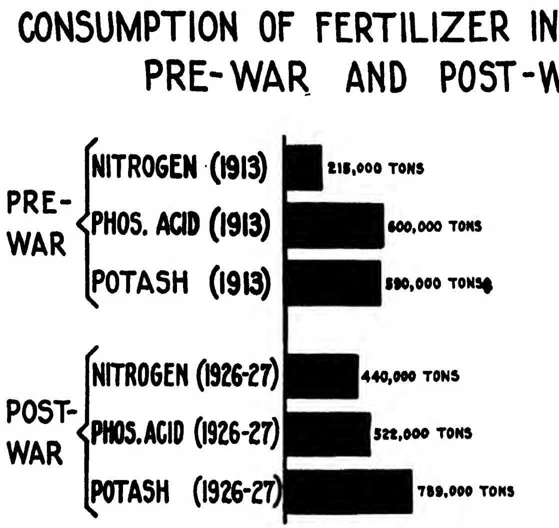


FIG. 1.

these two periods were, of course, the war years and the several years of readjustment following the war. Fertilizer consumption during these abnormal years is of interest from some viewpoints but will not be discussed or referred to in this paper. It is felt that the consumption during the years immediately preceding the war as compared with consumption during the past two or three years will disclose some trends that will be of interest to the readers of this JOURNAL.

[1]Paper read at the meeting of the Society held in Washington, D. C., November 23, 1928.

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In order that the picture may be as complete as possible, there is presented in Table 1 the pre-war and post-war consumption of nitrogen, phosphoric acid, and potash for four European countries, *viz.*, Germany, France, Holland, and Great Britain; for the United States; and for the world. These data are also presented graphically in Figs. 1, 2, 3, 4, 5, and 6.

In the fertilizer year 1913–14 the world consumption of nitrogen was 667,000 tons, while in 1926–27 it was 1,320,000 tons; in other words, nitrogen consumption has just about doubled since 1913.

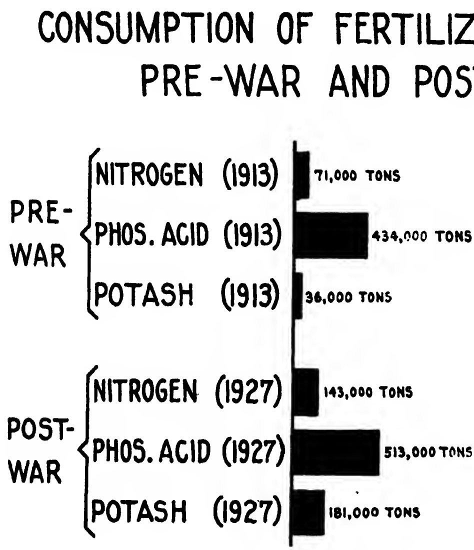


FIG. 2.

In 1913 the total world consumption of superphosphate was 11,810,000 tons; in 1925 it was 13,546,000 tons, or only a slight increase. The world consumption of basic slag declined from 5,910,000 tons in 1913 to 4,235,000 tons in 1925. The $P_2O_5$ content of these materials in 1913 was 2,952,000 tons; in 1925 it was 2,929,000 tons—a slight decrease. There were decided increases in Italy, Spain, France, and Australia, and considerable decreases in Germany and England.

The total consumption of potash increased from 1,104,000 tons of $K_2O$ in 1913 to 1,590,000 tons in 1927, or 44%. It is of interest to note that Germany uses almost exactly half the total potash consumed in the world.

Now, if all the fertilizing materials produced in the world were mixed together and standardized to contain 20% of total plant food,

the world ratio for 1913–14 would have been 2.8–12.5–4.7 and for 1925–27 it would have been 4.5–10.0–5.4. The total annual production of this hypothetical complete fertilizer in 1913–14 would have been 23,600,000 tons and in 1925–27 it would have been 29,200,000 tons, an increase for the period of about 24%.

TABLE 1.—*Pre-war and post-war consumption of plant food in short tons.*

| | Pre-war, 1913–14 | | | Post-war, 1925–27 | | |
|---|---|---|---|---|---|---|
| | Nitrogen | Phosphoric acid | Potash | Nitrogen | Phosphoric acid | Potash |
| The world.... | 667,000[1] | 2,952,000[8] | 1,104,000[3] | 1,320,000[2] | 2,929,000[8] | 1,590,000[9] |
| Germany..... | 215,000[5] | 600,000[5] | 590,000[5] | 440,000[4] | 522,000[4] | 789,000[4] |
| United States. | 209,000[11] | 715,000[11] | 256,000[6] | 310,000[11] | 751,000[11] | 269,000[7] |
| France....... | 71,700[5] | 434,000[5] | 36,000[3] | 143,000[2] | 513,000[2] | 181,000[10] |
| Holland...... | 18,700[2] | 97,600[2] | 48,000[3] | 46,000[2] | 120,500[2] | 100,000[10] |
| Great Britain. | 40,000[5] | 182,000[5] | 26,000[3] | 45,000[12] | 150,000[12] | 50,000[10] |
| Total for 5 countries. | 539,400 | 2,028,600 | 956,000 | 984,000 | 2,056,500 | 1,389,000 |

[1]Data presented International Nitrogen Conference, Biarritz, 1926, fertilizer year 1913–14.

[2]Handbuch der Internationalen Stickstoff und Superphosphat Industrie—1928; figures for years 1913 and 1926, respectively.

[3]Dr. P. Krische, in "Das Kali."

[4]Statistisches Jahrbuch fur das Deutsche Reich, 1927; page 59; figures for fertilizer year 1926–27.

[5]International Institute of Agriculture, Rome.

[6]Imports for use as fertilizer.

[7]Imports for use as fertilizer, plus American production.

[8]Handbuch der Internationalen Stickstoff und Superphosphat Industrie—1928, totals compiled for years 1913 and 1925 include $P_2O_5$ content of superphosphate and basic slag only. These materials were assumed to contain 16% and 18% of $P_2O_5$, respectively.

[9]Estimate by author with consumption known for Germany, France, United States, Holland, and England.

[10]Estimates by French, Dutch, and English representatives of the potash industry.

[11]Estimates by the author.

[12]Estimates secured by author from representatives of British nitrogen and superphosphate industries.

Pre-war consumption of plant food in the United States was 209,000 tons of nitrogen, 715,000 tons of phosphoric acid, and 256,000 tons of potash. In 1926 our consumption of nitrogen had reached 310,000 tons, of phosphoric acid 751,000 tons, and of potash 269,000 tons. These figures show a substantial increase in nitrogen consumption, but very small increases for phosphoric acid and potash. The ratio has shifted from 3.5–12.1–4.3 in 1913–14 to 4.7–11.3–4.0 in

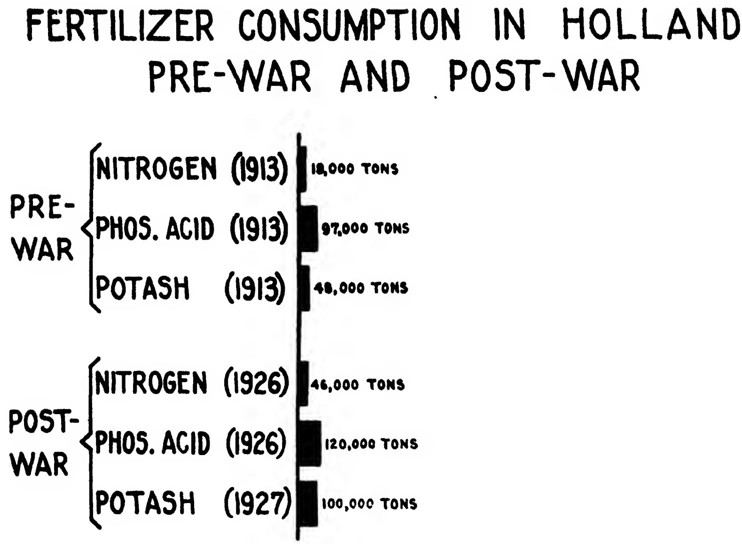


FIG. 3.

1925–27. The total increase in plant-food consumption during the 13-year period has been only about 13%, or an average of 1% per year.

In Europe the world war and post-war reconstruction and readjustments have brought about profound changes in the use of fertilizers,

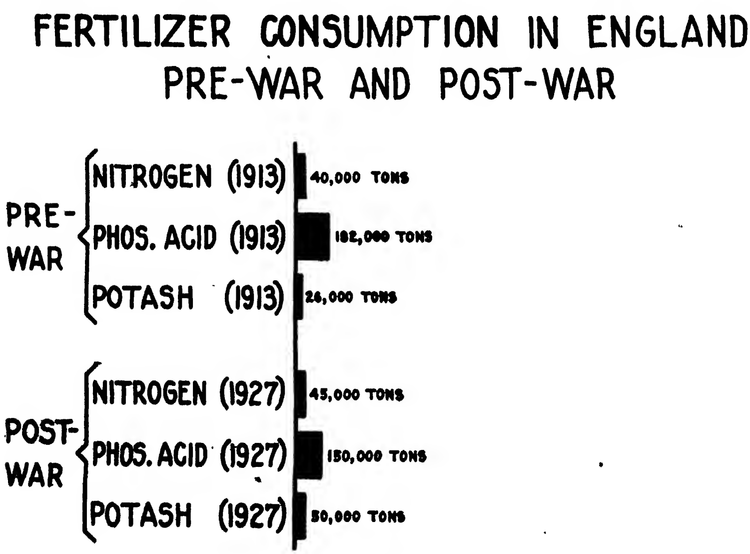


FIG. 4.

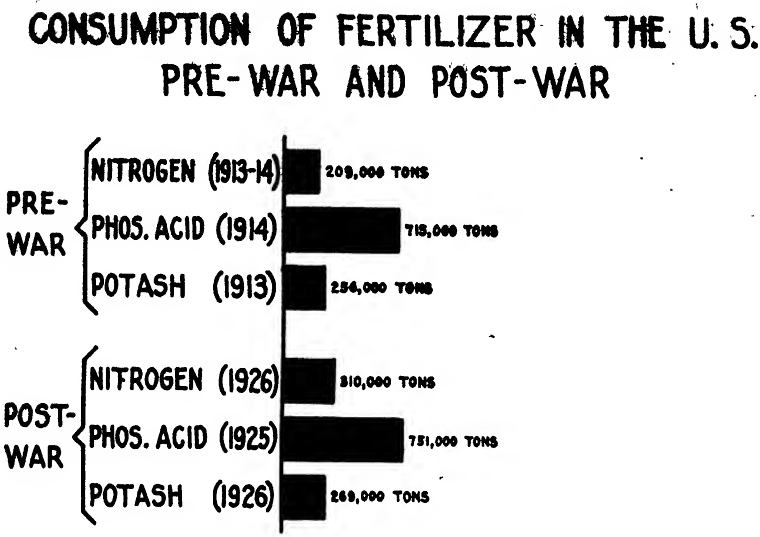


FIG. 5.

both as to rates of application and ratios used. In this brief paper I shall attempt to show the changes that have taken place in Germany, France, Holland, and Great Britain. These four countries and the United States consume three-fourths of all the fertilizer used in the world.

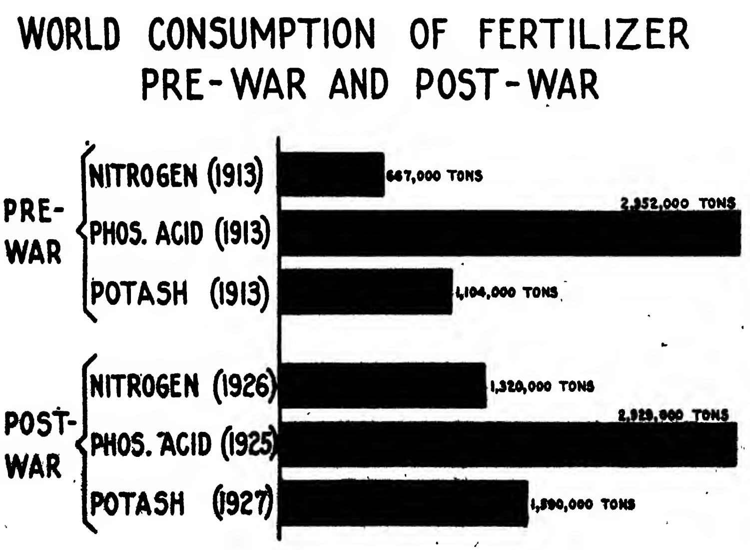


FIG. 6.

Germany is by far the largest consumer of fertilizer in Europe, having used in the fertilizer year 1926–27 30% of the total world consumption of plant food. In 1913 Germany used 215,000 tons of nitrogen, 600,000 tons of phosphoric acid, and 590,000 tons of potash. By 1926–27 the annual consumption of nitrogen had reached 440,000 tons and potash consumption had risen to 789,000 tons, but the consumption of phosphoric acid had dropped to 522,000 tons. This, however, is not the whole story, for during the war (1914 to 1918) and for some years after it the consumption of phosphoric acid was much less, and the consumption of nitrogen and potash continued to be relatively high.

In 1913 the plant-food ratio in Germany was 3.1–8.5–8.4 and the total consumption was equal to 7,025,000 tons of mixed fertilizer containing 20% of total plant food. In 1926–27 the ratio had shifted to 5–6–9 and the consumption had risen to 8,755,000 tons, an increase in total plant food of 24.6%.

France is now using exactly *twice as much nitrogen, five times as much potash,* and somewhat more phosphoric acid than before the war. In 1913 the consumption of nitrogen in France was 71,700 tons, of phosphoric acid 434,000 tons, and of potash 36,000 tons. The plant-food ratio was 2.6–16.0–1.3 and the total consumption, expressed in terms of a mixed fertilizer of the above ratio, was 2,711,000 tons. In 1927 the consumption of nitrogen in France was 143,000 tons, of phosphoric acid 513,000 tons, and of potash 181,000 tons. The ratio in 1927 was 3.4–12.3–4.3, and the total tonnage in terms of mixed fertilizer was 4,185,000 tons, representing an increase in plant-food consumption of 54.4%.

With rich phosphate deposits in her North African Colonies and her enormous potash deposits in Alsace, France, is admirably provided with supplies of fertilizer raw materials and will undoubtedly increase her consumption rapidly for some years to come.

Since 1913 Holland has multiplied her consumption of nitrogen by two and a half and her potash consumption by two, and she has ncreased by about 25% her use of phosphoric acid. In 1913 Holland used 18,700 tons of nitrogen, 97,600 tons of phosphoric acid, and 48,000 tons of potash. In 1926 she used 46,000 tons of nitrogen and 120,000 tons of phosphoric acid, and in 1927, 100,000 tons of potash. In 1913 the plant-food ratio in Holland was 2.3–11.9–5.8 and the total consumption was equivalent to 821,000 tons of mixed fertilizer of that analysis. In 1926–27 the plant-food ratio was 3.4–9.0–7.5 and the total consumption was equal to 1,325,000 tons of our hypothetical mixed fertilizer, representing an increase of 61% in total plant food consumed.

England is the only important fertilizer-using country that made no increase in its total plant-food consumption from 1913 to 1927. There has been a decided change in radio, however.

In 1913 Great Britain used 40,000 tons of nitrogen, 182,000 tons of phosphoric acid, and 26,000 tons of potash, while in 1927 the total consumption was 45,000 tons of nitrogen, 150,000 tons of phosphoric

PRESENT PLANT-FOOD CONSUMPTION PER ACRE OF CROP AND IMPROVED PASTURE AND HAY LAND

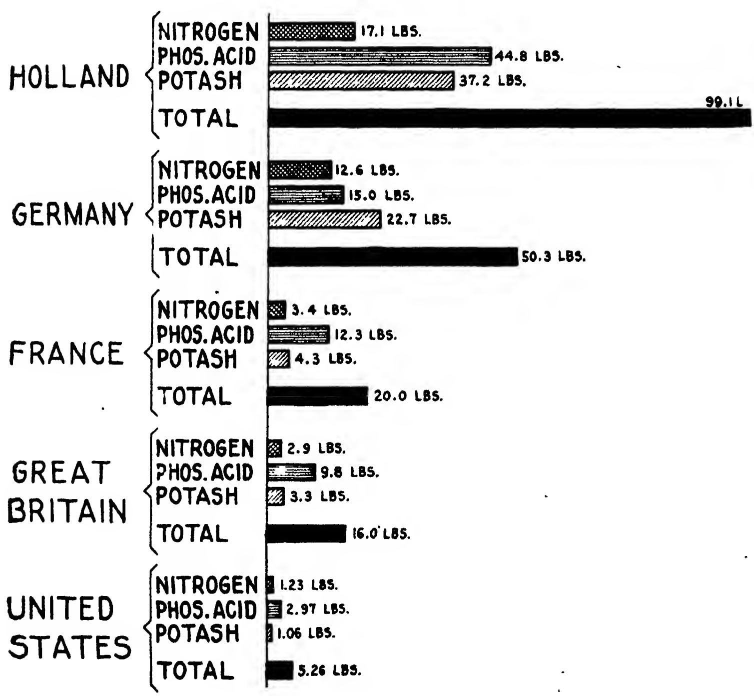


FIG. 7.

acid, and 50,000 tons of potash. The ratio in 1913 was 3.2–14.7–2.1, as against a ratio in 1927 of 3.7–12.2–4.1. The total consumption of plant food in England is, therefore, practically the same as before the war. The figures for 1927 are estimates, but they are based on information obtained from reliable sources.

In order to give a better picture of the use of fertilizer in the countries of the world, the quantity of plant food consumed per acre

of crop and improved pasture and hay land has been calculated (Fig. 7). Such comparisons are always more or less unsatisfactory, because agriculture is very different in different countries, but they help to give us a general picture, provided we are careful not to draw too many conclusions from them. For example, the land in Holland is practically all utilized either for intensive pasture or for crops, and there is much farming under glass with very high fertilization. The total acreage of crop and pasture land in Holland is only a little more than 5,000,000 acres. At the other extreme is the United States which has more than 500,000,000 acres of crop and plowable pasture land, over 200,000,000 acres of which is so situated as to rainfall that it cannot be fertilized with profit.

Another important development in the European fertilizer situation and one with which all are familiar, at least in a general way, is the change from the *nitrate* to the *ammonia* forms of nitrogen. This change involves consideration of soil reactions which are of interest to all agronomists and soil chemists, but which cannot be considered here in detail.

According to data presented at the International Nitrogen Conference in May, 1928, by Dr. J. Bueb, the world consumption of the various forms of inorganic nitrogen in 1913 and in 1926–27 was approximately as follows:

| | 1913 % | 1926–27 % |
|---|---|---|
| Chilean nitrate | 54 | 23 |
| Sulfate of ammonia (by-product) | 36 | 24 |
| Nitrate of lime (Norwegian) | 3 | 2 |
| Cyanamide | 4 | 14 |
| Synthetic ammonia | 3 | 37 |

TABLE 2.—*Consumption in short tons of inorganic nitrogen materials in Germany, France, Holland, and England for 1913 and 1926.*

| Countries | Year | Chilean nitrate* | Sulfate of ammonia* | Cyanamide* |
|---|---|---|---|---|
| Germany | 1913 | 821,000 | 558,000 | 42,000 |
| | 1926 | none | 1,140,000† | 460,000‡ |
| France | 1913 | 348,000 | 106,000 | 18,000 |
| | 1926 | 187,000 | 376,000 | 69,000 |
| Holland | 1913 | 91,000 | 21,400 | 1,700 |
| | 1926 | 142,000 | 109,000 | 3,300 |
| Great Britain | 1913 | 145,500 | 122,000 | 500 |
| | 1926 | 42,400 | 168,000 | 1,700 |

*Estimates of International Institute of Agriculture, unless otherwise noted.
†Using Lambert's estimated production of 1,500,000 metric tons.
‡Lambert's estimate.

Note that Chilean nitrate supplied over half of the inorganic nitrogen used in the world in 1913, but in 1926–27 less than one-fourth of it was derived from that source.

The consumption of the more important inorganic nitrogen materials for the years 1913 and 1926 is shown in Table 2 for Germany, France, Holland, and Great Britain.

The totals for nitrate of soda, sulfate of ammonia, and cyanamide for the four countries are as follows:

| | | |
|---|---|---|
| Nitrate of soda | 1913 | 1,405,000 tons |
| | 1926 | 371,000 tons |
| Sulfate of ammonia | 1913 | 807,000 tons |
| | 1926 | 1,793,000 tons |
| Cyanamide | 1913 | 62,000 tons |
| | 1926 | 534,000 tons |

These figures show the tremendous change that has taken place; in fact, they exaggerate the picture slightly, since small quantities of Norwegian nitrate of lime have been used for some years and the consumption of nitrate of soda in France in 1926 was below normal. Also, during the past two or three years production of calcium nitrate has increased rapidly in Germany, but unfortunately tonnage figures are not available.

The third important development in European fertilizer practice has been the tendency toward the use of complete fertilizers. This tendency is most pronounced in Great Britain, where from 50 to 60% of the entire tonnage is now factory-mixed. Some complete fertilizer is manufactured and sold in France, and although there is no good basis for estimating the percentage of the total tonnage of all fertilizers, certainly it is small. In Germany the Nitrogen Syndicate has been promoting the use of nitrophoska and during the last fertilizer year sold 165,000 tons in Germany. This is the equivalent of 500,000 tons of complete fertilizer containing 20% of total plant food or more than 5% of the total German consumption.

## SUMMARY

Since 1913 the world consumption of fertilizer nitrogen has doubled, the consumption of potash has increased over 40%, and the consumption of phosphoric acid has remained almost stationary.

In the United States there has been an increase of 13% in total plant-food consumption since 1913, and this is almost entirely accounted for by the increased use of nitrogen.

In Germany the consumption of nitrogen has more than doubled, potash consumption has increased 33%, and the use of phosphoric acid has declined 13%.

In France the present consumption of nitrogen is double the pre-war consumption, the use of potash has increased five-fold, and the consumption of phosphoric acid has increased only 16%.

Since 1913 Holland has multiplied her consumption of nitrogen by two and a half, her potash consumption by two, while her phosphoric acid has increased only 25%.

The total consumption of plant food in England is practically the same as before the war. Nitrogen consumption is about the same, the use of phosphoric acid has declined 17%, and potash consumption has practically doubled.

At the present time Holland uses 99 pounds of plant food per acre of crop and improved pasture and hay land as compared with 50 pounds per acre in Germany, 20 pounds in France, 16 pounds in England, and 5 pounds in the United States.

There has been a marked decline in the consumption of nitrates in Europe, especially in Germany, and a tremendous increase in the consumption of the ammonia forms of nitrogen.

There is a decided trend toward the use of complete fertilizers in Europe. In Great Britain from 50 to 60% of the fertilizer tonnage is factory-mixed and the use of complete fertilizers is on the increase. In France the sale of mixed fertilizer is very limited but increasing, and in Germany nitrophoska is making progress.

# SOIL AND LAND VALUATION SHORT COURSES[1]

W. H. STEVENSON AND P. E. BROWN[2]

Records show that the first Soil and Land Valuation Short Course in the Middle West, and probably in the United States, was held at Iowa State College, Ames, in April 1925.

This pioneer course was a modest affair but a distinct success. It was enthusiastically approved by the appraisers and others in attendance and the soils staff of the college was urged to put on a more comprehensive program in the following years. An earnest endeavor has been made to bring each succeeding course to a higher standard of efficiency. The programs have steadily improved and attendance records have been most gratifying. For example, 60 were present in 1925; 70 in 1926; 100 in 1927, and approximately 200 in 1928. It is believed that these attendance figures are significant. Busy appraisers and high-salaried bankers and insurance company officials will not leave their regular duties for two or three days during a rush time of the year, in steadily increasing numbers, to attend short courses, unless the programs are made up of discussions on up-to-date subjects of vital importance to those who appraise farm lands or make loans on the basis of such appraisals.

## WHY THE FIRST COURSE WAS OFFERED

In the late fall of 1924, a middle-aged, experienced land appraiser, who was a total stranger, called at the office. This appraiser stated that his experience in the field made it very clear that he lacked a knowledge of soils in general and especially of those found in the region in which he made appraisals. He said that he needed to learn many things about the origin, formation, classification, physical and chemical characteristics, distribution, fertilizer needs, crop-producing power, and relative values of soils. This appraiser found it impossible to attend regular college classes. "Could we help him?" The reply was made that the college would put on a two- or three-day short course along the lines that had been suggested if he would arrange to bring at least a dozen appraisers with him to the meetings. The promise was given and the program for the first course was arranged and announced. Sixty people registered, paid a small fee, and attended the meetings that covered a period of three days.

[1]Paper read at the annual meeting of the Society held in Washington, D. C., November 23, 1928. Contribution from Soils Department, Iowa State College, Ames, Iowa.

[2]Professor of Farm Crops and Soils and Professor of Soils, respectively.

This brief story with reference to the origin of the Ames series of Land Valuation Short Courses has been related here, because it shows that our work has been based from the beginning on a real and recognized need on the part of appraisers for additional information regarding soils and the factors that determine the agricultural value, and hence the loan value, of lands. It is believed that our courses have been successful because the work that has been offered has been elementary, practical, adapted to the needs of appraisers, and of tangible value to mortgage bankers, insurance company officials, and investors.

Our experience, based on four annual courses, contacts with scores of appraisers, and conferences with a large number of officials who are responsible for loans on farm lands, brings the conviction, "that one of the most vital factors in mortgage lending is the employing of better trained appraisers and training present appraisers more carefully." A careful study of the whole problem of the better preparation of appraisers for their fundamentally important work leads to the conclusion that Land Valuation Short Courses are almost certainly the most useful and efficient agencies that can be set up to provide the training needed by appraisers and their associates. The work that has been done in Iowa during the past four years proves that such courses can be made to conform to the needs of appraisers and those associated with them in the farm loan field. It is believed, therefore, that this is an auspicious time for this organization to take the lead in helping some strategically located agricultural colleges to establish courses of instruction for appraisers and loan company officials with the emphasis on soils and well-balanced programs.

## WHAT CAN A LAND VALUATION SHORT COURSE DO FOR LAND APPRAISERS?

Thoughtful appraisers are on record with reference to their need for more information about soils. Short courses that have been held in Iowa and in a few other states show in part what agricultural colleges, with efficient soils staffs, can do to meet these needs.

The work offered at the 1928 course at Ames may be used to illustrate how a carefully outlined program may be helpful and inspiring to appraisers and others who are interested in farm loans.

### 1. FIELD CHARACTERISTICS OF SOILS

From the very first the appraisers who have attended the Ames meetings insisted that they needed and wanted a large amount of elementary instruction regarding the field characteristics of soils with

particular reference to texture, structure, color, plasticity, plant-food content, and the influence of these factors on the water-holding capacity, tilth, and fertility or crop-producing powers of soils. Studies along these lines have been stressed and have met with the hearty approval of the appraisers.

### 2. A STUDY OF SOIL TYPES AND SURVEYS

Iowa has under way a state-wide detailed soil survey. Its primary purpose is to survey and map all of the soil types in the state. At this time 53 county soil reports, based on the survey, are available. Each report contains a map of the county with the location of every soil type shown thereon, a complete description of the physical characteristics of each type, and a statement regarding its agricultural value. It is obvious that data of this kind, if properly interpreted, are of the greatest value to appraisers. At the Ames short course a special effort has been made to set forth clearly the facts about the value of the soil surveys and to give careful instruction in the use of the maps and accompanying descriptions of the various types. Many appraisers and loan company officials have stated that they have found this part of the short course work of special value and that they daily use our maps and reports in the field and in the office.

About a year ago an official of a large insurance company, in charge of farm loans, visited our office. He said he made large use of the Iowa soil maps but now needed a list of the soil types of the state that classified the various soils as "good," "medium," and "poor." A grouping of Iowa soils was made on this basis and the results were presented at the short course in May of this year. This part of the program was of special interest and illustrates at least one way in which specialized instruction in soils may meet the needs of farm loan people.

### 3. FIELD TRIPS

A field trip constitutes one of the high lights of every Iowa short course. It affords an unequaled opportunity to drive home some important lessons. For example, the instructors are enabled to illustrate the use of the soil auger and prove that it is an indispensable part of an appraiser's equipment. This has been done repeatedly by our staff. The appraisers have been taken to a cultivated area, where the topography, surface soil, crop conditions, and other factors seemed ideal. But the use of an auger quickly showed the presence of much sand and gravel in the lower layers of the upper 3-foot zone. The discovery of this material indicated at once that the loan value of this soil could not be placed at a figure more than half as high as

would be fixed for a soil as good as it was believed at first was under consideration. Every report turned in by an appraiser should give an accurate description of every soil found on the farm to a depth of at least 3 feet. All dependable soil surveys are made on this basis. We shall not have accurate and high class appraisal work until this is done.

A field trip also makes it possible to show appraisers various soil types under actual field conditions, to call attention to their more important characteristics, and to point out how each of these influences the crop-producing power and loan value of each type. This feature of the work is of special value because it is impossible to get an accurate understanding of soil types from a laboratory study.

Field trips also give appraisers an exceptional opportunity to secure some excellent training in actual field work with or without the use of a score card. A card has sometimes been used at Ames which was designed to call the appraisers' attention to the important points about soils that should be considered in a field inspection. This type of training is worthwhile and deserves a place on every short course program.

### 4. SOIL MANAGEMENT PROGRAMS

The 1928 short course emphasized the fact that appraisers can secure a valuable fund of information concerning soils and appraisal values from a study of soil fertility problems and soil management programs that deplete or build up the crop-producing power of soils. For example, instructors discussed at some length certain soil management practices which lessen production and reduce land values and hence should be carefully considered in the preparation of an appraisal report. It was pointed out that the producing power of a farm does not remain constant, that it either increases or decreases with the years, and that it is certain that bad systems of soil management decrease crop yields. The result over a short period of time may not be such as to influence values in a large way, but in the case of long-time loans this factor becomes one of considerable importance.

The fact was also stressed that a soil management program of the right type is of great interest to people who place farm loans because its use on a farm is a guarantee that the fertility of the soils on that farm can be maintained and, in most cases, increased with a minimum outlay of time and money.

This part of the short course program gives the staff an opportunity to present valuable data from soil experiment fields that show definitely the extent to which soil management of the right type builds up

fertility, increases crop yields, and stabilizes the loan value of the land. The writers emphasize this point of soil management in relation to loans, because it is believed that the time is here when loan companies should rank two farms *located on the same soil type* very differently if widely varying soil management practices have been followed, one good, the other bad.

### 5. ORIGIN AND CHARACTERISTICS OF SOILS

Without doubt one of the most popular, interesting, and valuable subjects on a Land Valuation Short Course program is one dealing with the origin and characteristics of soils. Many appraisers want this subject discussed every year. It was not included in the 1928 program but will be found on the next program because of the large number of demands that have been made for this work. It is believed that the appraisers who want this training realize that this subject, if handled in the proper manner, gives them a wealth of information about the soils of an area, such as a state, that can be used in connection with every inspection trip and every report that they prepare.

This subject has been presented by using an accurate soil map of the state on which is shown the principal soil areas and the distribution of the more important soil types. With this map the instructor can easily point out the striking variations in the soils of the area and call attention to the outstanding characteristics of each type that have an important bearing on loan values. An appraiser who is well trained along these lines has a working knowledge of soils that is priceless. It enables him to appraise soils with confidence and accuracy.

The great value of this type of training was strikingly revealed about two years ago. The manager of the farm loan department of one of the largest life insurance companies of the United States made a trip to Ames for a conference regarding the soils of Iowa, with special reference to farm loans. The soil map was placed on the desk. A certain area was pointed out and the statement was made by a member of the soils staff that some of the soils therein were not very productive and called for special attention from a loan standpoint. "Yes," the insurance company official said, "We have noted that fact; we make few or no loans in that area." The conference proceeded with the same results in every similar case. We scarcely need add that the company that this man represents has one of the finest farm loan records in the country.

The following facts concerning soil conditions in Iowa illustrate the type of valuable data that appraisers may get from a study of the soils of the state.

1. On the river and lake terraces throughout the state there occurs a soil type called O'Neill loam. As a rule this type is an attractive, dark brown, mellow loam at the surface, is level, and in the spring and early summer produces a fine-looking crop; but as the dry season comes on the crop suffers materially because of a lack of moisture. If the season continues dry for a long period of time, the crop will be almost a complete failure. The O'Neill loam soils have a sand and gravel subsoil usually 25 to 30 feet in thickness which fails to retain moisture. A farm that has a considerable acreage of this type has a low loan value. The O'Neill loam will often deceive an appraiser who is not trained to identify it in the field.

2. In the Wisconsin Drift Area in northern Iowa many peat and muck deposits are found. These soils are discriminated against by farmers because of the difficult soil management problems involved.

A few years ago a farmer purchased a 240 acre farm in northern Iowa. This farm has 120 acres of good mineral soil and 120 acres of peat, ranging from 1½ to 3 feet in depth. A loan company placed a first mortgage of $125 per acre on this farm. Today the whole farm could be bought for about $75 per acre. In this case if the appraiser had been trained to detect peat deposits and had been fully posted on the extent to which they generally affect loan values, his company would not face a loss such as has just been noted.

3. Throughout southern Iowa there are many outcrops of Kansan till. This material is a tight boulder clay, almost wholly impervious to water. When it becomes saturated it is so sticky that plowing is a difficult operation. These outcrops are called "push" soils and are generally quite unproductive. On some farms this type occurs in so many areas that the value of the land as a whole is materially lowered. Every man who appraises land in southern Iowa should know about "push" soils and his reports should show clearly the acreage of these soils on each farm.

4. In several sections of the state sandy soils are found, such as Dickinson, Lindley, Pierce, Carrington, and Clarion. As a rule these soils are low in organic matter and plant food and are droughty. The surface soil at certain seasons of the year tends to blow to such an extent that crops often cannot be started on them successfully. Such soils are of little agricultural value and their location and characteristics should be definitely known by appraisers.

### 6. OTHER SUBJECTS OF VALUE

Some subjects in addition to those listed above are needed to develop a well-balanced Land Valuation Short Course program. We recommend one or two talks in the field of agricultural economics.

Two of this type that have been popular at Ames were entitled "Some Long Time Aspects of Land Valuation" and "The Iowa Farm Mortgage Situation to Date." Other interesting and valuable papers were entitled "The Right Type of an Appraisers' Report," "Noxious Weeds," "Factors in an Efficient Drainage System," and "The Operation of Foreclosed Farms." At Ames the chief emphasis from the first has been placed on a study of soils with special reference to physical and chemical characteristics, soil types and profiles, the appraisal value of abnormal soils, such as peat, alkali, gumbo, and sands, and the use of soil survey maps and reports. But experience shows clearly the value of discussions that deal with the drainage, erosion, and weed problems and certain phases of agricultural economics. In order to present something of special interest to the large group of mortgage bankers and insurance company officials that attend the meetings, men from these fields have been asked to speak on subjects that are of peculiar interest at the time. For example, just now probably no topic at a land valuation meeting will be discussed with more interest and enthusiasm than that of the management of foreclosed farms. This is a tremendous problem and one that merits the best thought that keen minds can bring to its consideration.

## ADDITIONAL LAND VALUATION SHORT COURSES ARE NEEDED

Land valuation short courses or meetings of a somewhat similar character have been held in Iowa, Missouri, Nebraska, and a few other states. The attendance at Ames has reached the 200 mark. Ten states were represented in 1928, namely, Iowa, Illinois, South Dakota, Indiana, Wisconsin, Nebraska, Missouri, Minnesota, North Dakota, and Vermont. The following summary of the various commercial interests represented at the last course shows definitely the groups that are interested in and attend a land valuation meeting that has a well-balanced program.

| | Number of representatives |
|---|---|
| Bond and mortgage companies | 51 |
| Insurance companies | 33 |
| Iowa bankers | 33 |
| Federal and joint stock land bank appraisers and executives | 26 |
| Other loan agencies | 28 |
| Farmers | 5 |
| Real estate men | 5 |
| Highway officials | 3 |
| County agents | 2 |
| Fertilizer companies | 2 |

The data here presented are given for the purpose of showing that within the brief period of four years the work of a well-organized land valuation short course has won the hearty approval of a large group of people who are connected with the farm loan business. Every phase of the business has been represented.

This record of accomplishment has been noted by some of the leaders in the farm mortgage field. These men believe that work of the general type offered at Ames should be made available to large groups in many states. In an effort to increase the number of effective land valuation short courses in this country the Board of Governors of the Morgtage Bankers Association of America has appointed a committee to confer with representatives of agricultural colleges. This is a constructive and forward-looking action. It is undoubtedly based on the belief that systematic education along lines of farm land appraisals, with emphasis on soils and soil characteristics, is worth while and will help to place the farm loan business on a more satisfactory and profitable basis.

# COOPERATIVE ROD-ROW WHEAT TRIALS IN NORTH DAKOTA FOR 1928[1]

L. R. WALDRON[2]

In this paper a brief report is presented of results from cooperative rod-row wheat trials conducted in North Dakota in 1928, following a report[3] for similar experiments in 1927. A consideration of rust injury is also included.

Ten varieties of wheat were grown in rod rows which were quadruplicated and unguarded in all cases but two, where they were grown triplicated in guarded rows. In these two cases, additional varieties were added to the experiment. Forty-five lots of wheat were sent out and threshing data were secured on 28 lots, 7 more than in 1927. In the 1928 series of experiments, the work was undertaken at 21 localities by farmers, at 19 localities by Smith-Hughes instructors, and at 5 localities by men in state institutions.[4]

Data were presented in the 1927 report tending to show that this method of rod-row work gave reasonably reliable results. It is possible at this time to furnish additional evidence upon this matter. The kinds of wheat selected for the work of 1928 were fewer in number with the result that a greater number of localities had the same quotas of wheat. By reason of this, it was possible to determine in a more satisfactory manner the correlation existing between yields of any two localities. As local conditions would enter in to affect the yields of any locality, only a reasonable amount of correlation could be expected. In a series of inter-locality correlations of this nature, two regions might enter into the comparison not equally adapted to the same varieties of wheat. Correlation between these two localities would thereby become reduced.

One set of coefficients was secured in eastern North Dakota between the seven localities of Mooreton, Edgeley, LaMoure, Cleveland, Carrington, Valley City, and Arthur. The coefficients are shown in Table 1.

[1]Contribution from the North Dakota Experiment Station, Fargo, N. Dak. Published with the approval of the Director. Received for publication December 27, 1928.

[2]Plant Breeder.

[3]WALDRON, L. R. Results from cooperative rod-row wheat trials in 1927. Jour. Amer. Soc. Agron., 20:500–510. 1928.

[4]The limits of this article preclude a detailed list of those participating and individual acknowledgment of work. A detailed list can be supplied upon request. The cordial assistance rendered by the cooperators is hereby gratefully acknowledged.

TABLE 1.—*Twenty-one correlation coefficients calculated for 10 varieties of wheat from seven localities in eastern North Dakota.*

| Combination | Coefficient | Combination | Coefficient |
|---|---|---|---|
| Mooreton-Edgeley.... | 0.61±0.13 | LaMoure-Cleveland | 0.13±0.21 |
| Mooreton-LaMoure... | 0.41±0.18 | LaMoure-Carrington | 0.71±0.11 |
| Mooreton-Cleveland... | 0.63±0.13 | LaMoure-Valley City | 0.33±0.19 |
| Mooreton-Carrington.. | 0.60±0.14 | LaMoure-Arthur | 0.59±0.14 |
| Mooreton-Valley City. | 0.92±0.03 | Cleveland-Carrington | 0.59±0.14 |
| Mooreton-Arthur..... | 0.92±0.03 | Cleveland-Valley City | 0.32±0.19 |
| Edgeley-LaMoure..... | 0.76±0.09 | Cleveland-Arthur | 0.41±0.18 |
| Edgeley-Cleveland.... | 0.18±0.21 | Carrington-Valley City | 0.39±0.18 |
| Edgeley-Carrington... | 0.62±0.13 | Carrington-Arthur | 0.63±0.13 |
| Edgeley-Valley City... | 0.63±0.13 | Valley City-Arthur | 0.92±0.03 |
| Edgeley-Arthur....... | 0.76±0.09 | | |

Fourteen of the 21 coefficients are significant; 6 of them are above 0.70. Of the seven coefficients lacking significance, six are concerned with either LaMoure or Cleveland. At LaMoure, hybrid selections of 1656 yielded low, which was probably brought about by heavy lodging. The yield of the durum (Mindum) was below the average of the 10 wheats grown at Cleveland, a marked contrast to its yield rank at other localities.

In western North Dakota, coefficients like the above were calculated for 10 varieties for several localities. These coefficients are given in Table 2.

TABLE 2.—*Twenty-one correlation coefficients calculated for 10 varieties of wheat from seven localities in western North Dakota.*

| Combination | Coefficient | Combination | Coefficient |
|---|---|---|---|
| Manning-Hazen....... | 0.23±0.20 | Mandan-New Salem....... | 0.84±0.06 |
| Manning-Mandan..... | 0.84±0.06 | Mandan-New England.... | 0.81±0.07 |
| Manning-New Salem.. | 0.52±0.16 | Mandan-Chantapeta...... | 0.57±0.14 |
| Manning-New England | 0.67±0.12 | Mandan-Watford City.... | 0.31±0.19 |
| Manning-Chantapeta.. | 0.80±0.80 | New Salem-New England.. | 0.62±0.13 |
| Manning-Watford City | 0.58±0.14 | New Salem-Chantapeta... | 0.39±0.18 |
| Hazen-Mandan....... | 0.16±0.21 | New Salem-Watford City.. | 0.34±0.19 |
| Hazen-New Salem..... | 0.39±0.18 | New England-Chantapeta. | 0.45±0.17 |
| Hazen-New England.. | 0.44±0.17 | New England-Watford City | 0.06±0.21 |
| Hazen-Chantapeta.... | 0.59±0.14 | Chantapeta-Watford City. | 0.72±0.10 |
| Hazen-Watford City.. | 0.26±0.20 | | |

Eleven of the 21 coefficients in Table 2 show significance, and 5 are above 0.70. Of the 10 combinations which are not significant, Hazen enters into 5 and Watford City into 4. Hazen and Watford City form one coefficient. The Hazen yields are not satisfactory as indicated by the very large probable error of 12.38%. This high probable error, combined with rather discordant correlation, indicates that some of the Hazen yields did not reflect actual yielding capaci-

ties. Watford City yields differ particularly from those of the other localities in that the durum variety (Nodak) ranked first in yield with an excess of 5.8 bushels above the Watford City average, while for the six other localities Nodak averaged 2.3 bushels below the average of the means. Seasonal and soil conditions were likely very favorable for durum at Watford City.

Considering the coefficients of Tables 1 and 2, the statement seems warranted that the yields in general reflect very well the actual yielding capacities of the wheats at the various localities.

## PROBABLE ERRORS

Probable errors were determined for all experiments by calculating from the standard deviation in the usual way. The standard deviation was calculated by the formula:

$$\text{S. D.} = \sqrt{\frac{\Sigma(d^2)n}{N(n-1)}}.$$

In most cases $N=40$ and $n=4$. The limits of this article forbid the presentation of detailed yield and other data and in the summarized yields combined probable errors will be presented. The 28 separate probable errors in per cents are shown herewith grouped into classes.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Class values... | 2–3 | 3–4 | 5–6 | 7–8 | 9–10 | 11–12 | Mean |
| Probable errors | 3 | 14 | 6 | 0 | 4 | 1 | 6.36 |

Five of the errors are strikingly high. In two of these cases, it is known that the severe spring drought delayed germination of some of the rows for such a period that yields were markedly affected. At Valley City, this effect was limited mainly to one replication. Except these five, the probable errors are well within the limits secured under standard experimental conditions.

For the sake of brevity, only averages of yields, bushel weights, and stem rust will be given and for this purpose those localities will enter in to each series of averages which will afford comparisons for each variety used. In Table 3, containing these data, the area of the state concerned in each series is broadly indicated. The combined probable error is shown for each series.

Ceres and the 1656 selections came from a Marquis-Kota cross made by the writer. Hope, Reward, Reliance, and Marquillo are varieties selected from known crosses recently introduced. They have all been registered by the American Society of Agronomy. The variety Hope, as is well known, is characterized by almost complete freedom from stem rust.

TABLE 3.—*Averages of yield, bushel weight, and stem rust of 10 varieties of wheat grown at 28 localities in North Dakota in 1928.**

| | State-wide | | | Northeast area | | | State-wide, except N. E. area | | | Western area | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Number of experiments | 28 | | | 9 | | | 20 | | | 12 | | |
| P. E., % | 1.32 | | | 2.29 | | | 1.53 | | | 1.92 | | |
| Variety | Yield in bushels per acre | Weight per bushel, pounds | Rust % | Yield in bushels per acre | Weight per bushel, pounds | Rust % | Yield in bushels per acre | Weight per bushel, pounds | Rust % | Yield in bushels per acre | Weight per bushel, pounds | Rust % |
| Marquis | 22.6 | 58.8 | 18 | 27.5 | 59.9 | 28 | 20.3 | 58.5 | 15 | 20.3 | 59.1 | 14 |
| Ceres | 28.4 | 58.6 | 2 | 31.6 | 58.8 | 4 | 26.4 | 58.5 | 2 | 27.2 | 59.2 | 2 |
| Hope | 21.8 | 56.2 | 0 | 25.1 | 56.7 | 0 | 20.2 | 56.0 | 0 | 19.9 | 56.1 | 0 |
| Reward | — | — | — | — | — | — | 18.4 | 60.0 | 7 | 19.9 | 60.4 | 7 |
| 1656.6 | — | — | — | 25.2 | 59.4 | —1 | — | — | — | — | — | — |
| 1656.44 | 22.6 | 58.3 | —1 | 25.5 | 58.9 | 1 | 20.9 | 58.1 | 1 | 21.7 | 58.5 | —1 |
| 1656.48 | 25.3 | 57.8 | —1 | 28.6 | 58.3 | 2 | 23.6 | 57.6 | 1 | 24.1 | 58.5 | —1 |
| 1656.84 | 25.3 | 57.9 | 2 | 27.0 | 57.7 | 2 | 23.9 | 58.0 | 1 | 25.5 | 59.0 | 1 |
| 1656.85 | 24.1 | 58.2 | —1 | 27.6 | 58.7 | 1 | 22.3 | 58.1 | —1 | 22.5 | 58.7 | —1 |
| Reliance | — | — | — | — | — | — | — | — | — | 27.5 | 60.2 | 9 |
| Marquillo | — | — | — | 26.6 | 56.8 | 5 | — | — | — | — | — | — |

| Variety | Eastern area | | | State-wide, except S. W. area | | | Southwest area | | |
|---|---|---|---|---|---|---|---|---|---|
| Number of experiments | 16 | | | 17 | | | 7 | | |
| *P. E., % | 1.80 | | | 1.75 | | | 2.52 | | |
| | Yield in bushels per acre | Weight per bushel, pounds | Rust % | Yield in bushels per acre | Weight per bushel, pounds | Rust % | Yield in bushels per acre | Weight per bushel, pounds | Rust % |
| Marquis | 24.3 | 58.5 | 22 | 25.3 | 58.7 | 20 | 18.1 | 58.7 | 16 |
| Ceres | 29.2 | 58.1 | 3 | 29.9 | 58.0 | 2 | 26.5 | 59.5 | 1 |
| Hope | 23.3 | 56.2 | 0 | 24.1 | 56.1 | 0 | 18.2 | 59.0 | 0 |
| Reward | — | — | — | — | — | — | 18.5 | 60.5 | 9 |
| 1656.6 | 23.6 | 58.8 | —1 | — | — | — | — | — | — |
| 1656.44 | 23.3 | 58.1 | —1 | 24.1 | 58.0 | —1 | 22.5 | 58.5 | —1 |
| 1656.48 | 26 6 | 57.2 | 1 | 26.2 | 57.1 | 1 | 23.9 | 59.1 | —1 |
| 1656.84 | 25.2 | 57.0 | 2 | 25.7 | 56.8 | 1 | 24.5 | 60.0 | 2 |
| 1656.85 | 25.3 | 57.7 | 1 | 25.2 | 57.7 | —1 | 21.8 | 59.1 | 1 |
| Reliance | — | — | — | — | — | — | 24.8 | 60.4 | 10 |
| Mindum | — | — | — | 32.4 | 61.4 | 2 | — | — | — |
| Nodak | — | — | — | — | — | — | 20.9 | 58.9 | —1 |

*The complete data in mimeographed form can be furnished by the writer upon request.

In the state-wide series, seven wheats are compared and in this comparison Ceres is highest yielding with an excess of $3.1 \pm 0.50$ bushels over 1656.48 and 1656.85, the two next highest. Likewise, these two have a similar excess over Marquis of $2.7 \pm 0.45$ bushels. In the 28 possible comparative yields between Marquis and Ceres, the latter yielded highest at 26 localities, equalled Marquis at 1 locality and at 1 place, Knox, it yielded less than Marquis. In 1927, 1656.85 outyielded all other common wheats, differences being most striking in areas of severest rust. In 1928, this wheat yielded significantly more than Marquis by $1.5 \pm 0.44$ bushels.

Marquillo was grown in northeastern North Dakota at eight localities, and at Edgeley. Mindum does not enter into this comparison with Marquillo as its yield was lost at Langdon. In this district, Ceres does not show so great a lead over Marquis as it does in the state-wide data, but its relation to the other wheats is about the same.

Reward, an early Canadian variety, was carried in 20 of the experiments. It yielded lowest of the eight wheats that are comparable, but its bushel weight was highest. Reliance, grown in 12 localities in the western area, was the only common wheat yielding as much as Ceres, actually yielding 0.3 bushel more and with an excess weight per bushel of 1 pound. Reliance yielded less than Ceres in 1927, due to the greater amount of rust carried by it. Over three-fourths of the state, Mindum outyielded Ceres by $2.5 \pm 0.77$ bushels; but Nodak, grown in southwestern North Dakota, yielded much below Ceres, but outyielded Marquis by $2.8 \pm 0.70$ bushels.

## RUST STUDIES

Readings of stem rust and determination of bushel weights were made at Fargo upon all lots. A study of these in connection with yields should be of value. In 1927, it was possible to establish very definite relations between stem rust and yields in susceptible and resistant varieties. Methods of measuring rust losses are even more complete for 1928 due to the greater number of localities represented and to the presence of the Hope variety, grown with Marquis at all points. But due to the smaller amount of rust and to its sporadic occurrence, conclusions in 1928 are less easily drawn. In one instance, at Rolla, Marquis carried 60% rust, but Marquis weighed 61.5 pounds per bushel in comparison to 4% rust carried by Ceres and a bushel weight of 58.0 pounds. While in this case, bushel weights indicate no rust injury, Ceres yielded 7.7 bushels more at Rolla than Marquis. At Manning, Marquis carried 61% of rust and Ceres 9%. This was the maximum amount of rust for Marquis at any place.

Weights per bushel of the two wheats were 55.5 and 57.0 pounds, respectively, while corresponding yields were 23.3 and 41.0 bushels. These figures indicate real rust injury, but Hope yielded 3.0 bushels less at Manning than Marquis. There was considerable lodging at Manning and Hope, although its straw is reasonably strong, might be easily influenced in yield by lodging.

The means and standard deviation of the Marquis and Ceres rust readings for the 28 localities were:

| | Marquis | Ceres |
|---|---|---|
| Mean | $18.48 \pm 2.22$ | $2.42 \pm 0.39$ |
| Standard deviation | $17.40 \pm 1.57$ | $3.05 \pm 0.27$ |

The variability in the amount of rust carried by Marquis was thus very marked. The same was true for Ceres, except that the maximum Ceres rust was 10% and at 12 localities Ceres carried zero or a trace.

The correlation was calculated between differences of rust between Marquis and Ceres and corresponding differences of yield. As Ceres is a resistant wheat, one would look for a positive correlation between these two variables if rust did injury to Marquis in correspondence to amount of rust present. The coefficient was found to be $0.36 \pm 0.11$ and seems a reasonable one, remembering that small Marquis rust readings would likely not depress yields. The corresponding coefficient for 1927 was calculated and found to be $0.60 \pm 0.10$.

Apparently, a better measure of rust injury would be a correlation between rust differences and yields, separating Marquis and Hope. As Hope had only zero or a trace of rust, the amounts of rust used in the correlation would be the readings of Marquis. This coefficient as calculated was found to be essentially zero, $0.0044 \pm 0.13$ to be precise. This coefficient would indicate no rust injury to Marquis in 1928, although, as stated, the Marquis samples average above 18% rust. A more intimate knowledge of the factors affecting yields of Hope might show that those working for rust development in Marquis affected Hope adversely in another direction. The yields of Hope, for example, may be easily affected by even moderate lodging. This lodging would be a consequence of weather conducive to rust development. Hope is more susceptible to the attacks of black chaff disease, but it is not believed that this was severe enough to modify yields appreciably.

If rust is not a sufficient factor in explaining the larger yields of Ceres compared with Marquis, other conditions must have entered. In the following article in this JOURNAL a somewhat detailed study of factors affecting yield is made and the results reported. A more extensive study of this sort is necessary before final conclusions can be reached.

SUMMARY

In the 1928 rod-row wheat trials conducted by volunteer cooperators, evidence is presented by correlation data that the results are reasonably consistent. The probable errors averaged 6.36%, and 23 of them are below 6%.

In the state-wide comparison, Ceres yielded significantly more than the other (common) wheats. In regional comparisons, Mindum yielded significantly more than Ceres, while the average yields of Ceres and Reliance were the same. In other regional cases, Ceres yielded significantly more than other wheats.

Correlation data between Marquis and Ceres show evidence of rust injury, but such injury is not indicated by correlation data obtained between Marquis and Hope.

# A PARTIAL ANALYSIS OF YIELD OF CERTAIN COMMON AND DURUM WHEATS[1]

L. R. WALDRON[2]

In this article an analysis is made of certain plant characters of spring wheat varieties grown at two localities in North Dakota. The characters have to do mainly with prolificacy. Correlation coefficients are presented between yield and certain other characters, and these are discussed. A discussion of means of these characters between certain variety-groups is also taken up.

It is shown that many varieties of common spring wheat do not possess one character of prolificacy, kernels per spike, in a degree sufficient to prevent lessened yields in comparison with other varieties possessing this character. It is evident, then, that full consideration must be given to breeding for high yields *per se*, in addition to breeding for disease resistance. The analyses given indicate that something has already been accomplished in this direction.

An increase of yield in farm crops is held desirable provided that the cost of increasing the yield is less than the value of the increased return. Particular stress is being laid upon elimination of disease by hybridization and subsequent selection. Evidently the introduction of new varieties, resistant or immune, relative to certain diseases, will result in increased yields in so far as previous yield deficiencies may have been caused by these diseases. Moreover, the cost of gains in yield increases of this nature will be relatively low.

In breeding thus for increased yield attention must be paid not only to disease elimination, but also to the production of varieties possessing an inherently high-yielding capacity. In the enthusiasm attendant upon disease elimination there is danger of neglecting high-yielding capacity.

In an analytical study of parents proposed, for the production of new varieties, it is possible to anticipate, in a measure, the probable outcome of the hybrid offspring as to their prolificacy, particularly number of kernels per spike. Nillson-Ehle (4)[3], in a thought-provoking article, has discussed the possibility of breeding for much higher cereal yields in northern regions than are now secured by using as one series of parents varieties of high-yielding capacity grown in southern regions. Percival (5) states that bearded wheats, especially those

[1]Contribution from the North Dakota Experiment Station, Fargo, N. Dak. Published with the approval of the Director. Received for publication December 27, 1928.

[2]Plant Breeder.

[3]Reference by number is to "Literature Cited," p. 309.

belonging to *T. vulgare erythrospermum*, give poor yields of grain with but very few exceptions. But low yields in spring wheat areas are not confined to this botanical variety for they are characteristic of such varieties as Marquis and Red Fife in comparison with more prolific winter varieties. But Biffen (1) believes that this defect in yield lies in a deficiency in kernels per spileket or spike.

The above suggestions seem particularly pertinent at present inasmuch as a great deal of work is now under way for the production of resistant varieties. Parental material is being sought over a wide range and the analyses suggested should be of importance, both theoretically and practically. As an example of parental diversity, two common wheats, Marquillo and Hope, have been introduced, the one by the Minnesota Experiment Station and the other by E. S. McFadden of South Dakota. Marquillo has the durum variety Iumillo entering into its parentage, while Hope claims Yaroslav emmer as one of its forbears. It is quite certain that the future will see other wheat varieties introduced resulting from chromosome combinations secured from these two species groups. Lately Meister (3) has advocated the common use of these two groups in intercrossing, pointing out advantages in the method.

## EXPERIMENTAL WORK

In 1928, from the wheat nurseries at Fargo and at Langdon, the latter under the charge of Supt. Victor Sturlaugson,[4] yard-row samples of certain varieties were given an analytical study with respect to certain characters. These studies were made upon 27 wheats grown at Fargo and upon the 20 grown cooperatively at Langdon. A typical yard row was selected of each sort studied, the plants pulled, and a count made of plants and fertile culms. Fifty uninjured heads, taken as they came, were used in making counts of number of fertile and sterile spikelets and number of mid-spikelets per spike. The weight of grain from 50 heads was determined and the weight per 1,000 kernels. An estimate was made upon plumpness. The detailed data for the 20 Langdon-grown varieties are given in Table 1.

As only a single yard of each kind was studied, results must be considered as only moderately representative so far as stand is concerned for each individual variety. Data upon head characters, such as number of spikelets per head where 50 units were studied, and upon weight per 1,000 kernels, are more reliable than stand data based upon a single yard.

[4]Thanks are due to Supt. Sturlaugson and to Glenn Smith for field notes on lodging, rust, etc., and for careful harvesting of the material for shipment.

TABLE 1.—*Yield, yard-row, and other data from the Langdon rod-row wheat experiments.*

| Name | Yields in bushels per acre | Lodging, 0–10 | Kernels per spikelet | Fertile spikelets per spike | Sterile spikelets per spike | Mid-kernels per spike | Total kernels per spike | Weight of grain per 50 heads, grams | Stools per plant | Plants per yard | Heads per yard | Weight of grain per yard, grams | Weight per 1,000 kernels, grams | Plumpness, 5–1 | Weight per bushel, pounds | Rust |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Durum | | | | | | | | | |
| Bot. 216 | 35.9 | 3 | 2.0 | 17.7 | 1.7 | 4.4 | 36.7 | 64.0 | 1.8 | 32 | 56 | 96.9 | 47.15 | 4 | 60.0 | T |
| Bot. 212 | 28.3 | 3 | 2.6 | 14.5 | 2.1 | 7.2 | 37.5 | 60.9 | 1.6 | 51 | 80 | 97.4 | 32.50 | 4 | 61.5 | T |
| Bot. 211* | 26.0 | 2 | 2.3 | 13.2 | 1.8 | 5.6 | 30.7 | 58.6 | 1.4 | 46 | 66 | 96.9 | 47.65 | 4+ | 64.5 | T |
| Mindum | Lost | 2 | 3.4 | 10.4 | 1.9 | 6.2 | 35.0 | 70.8 | 1.6 | 39 | 63 | 99.2 | 45.05 | 5 | 65.0 | 1— |
| | | | | | | | Common | | | | | | | | | |
| 1656.48 | 26.6 | 2 | 2.1 | 13.5 | 3.1 | 4.2 | 28.5 | 53.3 | 1.6 | 66 | 106 | 112.9 | 37.40 | 5 | 60.0 | 2 |
| 1656.85 | 26.2 | 2+ | 2.2 | 13.6 | 3.0 | 5.0 | 29.3 | 51.8 | 1.9 | 57 | 110 | 114.0 | 35.35 | 5 | 61.5 | 4 |
| 1656.118 | 25.5 | 1+ | 2.2 | 14.2 | 2.9 | 5.7 | 31.4 | 55.2 | 1.8 | 48 | 86 | 94.9 | 35.10 | 5 | 61.5 | 4 |
| 1656.44 | 23.3 | 2 | 2.1 | 13.1 | 2.6 | 4.2 | 27.4 | 44.7 | 1.5 | 60 | 88 | 78.6 | 32.60 | 5 | 61.0 | 1 |
| Ceres | 22.8 | 1 | 2.0 | 14.3 | 2.7 | 3.3 | 29.2 | 47.2 | 1.3 | 78 | 99 | 93.4 | 32.60 | 5 | 62.0 | 10 |
| Reward | 22.5 | 1 | 1.8 | 11.1 | 1.4 | 1.2 | 20.1 | 33.6 | 1.6 | 90 | 141 | 94.6 | 33.45 | 5 | 63.0 | 20 |
| 1656.84 | 21.8 | 1+ | 2.1 | 16.0 | 2.3 | 5.1 | 33.9 | 56.1 | 2.3 | 35 | 81 | 90.9 | 33.15 | 5 | 60.5 | 4 |
| 1656.6 | 21.7 | 1+ | 1.9 | 12.4 | 2.9 | 2.0 | 23.5 | 34.2 | 1.3 | 97 | 129 | 88.3 | 29.10 | 5 | 60.0 | T |
| Marquis | 21.7 | 1 | 1.8 | 14.8 | 2.4 | 1.3 | 26.3 | 44.7 | 1.3 | 73 | 98 | 87.7 | 34.05 | 5 | 62.0 | 25 |
| Bot. 209 | 21.3 | 2+ | 2.0 | 13.9 | 3.9 | 2.9 | 27.5 | 42.7 | 1.2 | 79 | 97 | 82.8 | 31.00 | 5 | 62.5 | 1 |
| Bot. 214 | 20.9 | 2 | 1.8 | 13.9 | 3.7 | 2.5 | 25.2 | 38.4 | 1.5 | 65 | 95 | 73.0 | 30.45 | 5 | 62.0 | 2 |
| Bot. 210 | 20.8 | 2+ | 2.0 | 13.8 | 3.7 | 3.8 | 28.0 | 44.2 | 1.2 | 92 | 109 | 96.4 | 31.60 | 5 | 62.5 | 1 |
| Bot. 215 | 20.6 | 1+ | 2.0 | 13.4 | 4.2 | 2.4 | 27.1 | 39.2 | 1.0 | 75 | 78 | 61.1 | 28.85 | 5 | 62.5 | 4 |
| Bot. 213 | 19.8 | 2 | 1.9 | 14.1 | 4.1 | 2.9 | 26.6 | 40.5 | 1.4 | 62 | 86 | 69.6 | 30.40 | 5 | 62.0 | 3 |
| Marquillo | 19.7 | 1 | 1.7 | 13.5 | 1.9 | 0.5 | 23.5 | 42.7 | 1.5 | 71 | 106 | 90.6 | 36.40 | 4+ | 59.5 | 5 |
| Hope | 19.3 | 1 | 1.7 | 13.8 | 3.4 | 0.4 | 22.9 | 40.1 | 2.4 | 49 | 116 | 93.1 | 35.00 | 4+ | 59.0 | 0 |

The Langdon data are taken first for discussion as these wheats were scarcely lodged and but little rusted, and therefore more normal in character than the wheats grown at Fargo which were badly lodged although nearly free from rust. The wheats numbered 1656 and the variety Ceres were selected by the writer (6) from a cross made between Marquis and Kota. The selection 1656.6 was badly infected with black-chaff disease at Langdon, which probably modified its grain weight to some extent. The yields at Langdon ranged from 19.3 to 28.3 bushels, except the durum, Bot. 216, which went 35.9 bushels. Mindum was injured before harvest and its yield was not usable. Five of the common wheats, Bot. 209, etc., came from seed furnished by H. L. Bolley. These appear to be similar in every way to the variety Kota. The uniformity of yield of these five wheats is striking and helps to emphasize the idea of their very close relationship to Kota. The natural weakness of straw of these wheats scarcely made itself evident. In the common wheats the number of fertile spikelets per head ranges from 11.1 for Reward to 16.0 for 1656.84, but these two wheats have nearly the same yield. The correlation between fertile spikes per head and yield is $0.52 \pm 0.11$, a positive and rather marked relationship. In some cases, as with Reward, fewer spikelets per head was compensated by other characters. The Kota selections had a striking number of sterile spikelets per head. The sterile spikelets of Ceres and the 1656 selections are mainly intermediate between Marquillo and the Kota selections. The correlation between number of sterile spikelets and yield was significantly negative, amounting to $-0.49 \pm 0.12$. Marked differences were found in number of mid-kernels per head, ranging from 0.4 in Hope to over 7 in one durum. The correlation of kernels per head and yield was found to be $0.73 \pm 0.07$, while that between mid-kernels and yield is $0.62 \pm 0.10$. The wheat 1656.84 has a very high kernel-per-head count, but its yield is below average. The square yard taken had a poor stand, and if representative, would account for the low yield.

Stools per plant is a character not showing much variability. The greater stooling of two of the common wheats, 1656.84 and Hope, may be due in part to thinner stand. The durums seem to show lesser stooling than the common wheats.

A study of the weights per 1,000 grains is of particular value because of the uniform high weights per bushel, indicating little or no damage from rust or lodging. Very little shrinking of kernels was in evidence and it appears that these weights per 1,000 are nearly typical of the various sorts. The weights of the 1656 selections and Ceres, omitting 1656.6, are about equal to Marquis, but considerably

above those of the Kota selections. The correlation of yield to weight per 1,000 kernels is 0.69±0.08, which is very significant.

In this connection, one should note the number of kernels per spike. Ceres and the 1656 selections, except 1656.6, equal the Marquis parent in weight per 1,000 kernels and exceed Marquis in number of kernels per spike. Also, these selections exceed the Kota selections in kernels per spike. This excess number of kernels per spike over either parent may be due to the larger number of mid-kernels, a Kota-like character, plus the fewer sterile spikelets per head, a Marquis character. Inasmuch as strong correlations are found both of kernels per spike and weight per 1,000 kernels with yield per acre, the high yields of the 1656 selections seem to be accounted for, at least under the Langdon conditions. The two varieties Marquillo and Hope have rather high weights per 1,000 kernels, but are low in kernels per head. Reward, with few kernels per spike, came through with an average yield by having a good stand, and good stooling, if the yard that was pulled was representative. The data of the yard samples from the wheat nursery at Fargo are shown in Table 2.

These data form a rather striking contrast, in some respects, with those just considered from Langdon. The same wheats are represented only in part at both places. The Fargo wheats were grown on rich soil and heavy storms in July caused severe lodging which persisted largely until harvest.

Correlation coefficients were determined between certain characters and yield for the Fargo-grown material. Taken in connection with similar coefficients for the Langdon material, comparisons are of interest. These are shown in the following tabulation:

| | Correlation between yield and | | | | | |
|---|---|---|---|---|---|---|
| | Fertile spikelets per head | Sterile spikelets per head | Kernels per head | Mid-kernels per head | Weight of grain per 50 heads | Weight per 1,000 kernels |
| Langdon | 0.52±0.11 | —0.49±0.12 | 0.73±0.07 | 0.62±0.10 | 0.79±0.06 | 0.69±0.08 |
| Fargo | 0.37±0.11 | —0.32±0.12 | —0.18±0.13 | —0.30±0.12 | 0.54±0.09 | 0.76±0.05 |

Those coefficients less than 0.35, either plus or minus, lack significance. Except for weight per 1,000 kernels, the Langdon coefficients are the most pronounced. Attention is called to the two negative coefficients at Fargo between yield and kernels per head and number of mid-kernels. The increased number of kernels per head does not tend to decrease yield, but in this case certain wheats, particularly the selections of 1656, were more injured by lodging or lodged more severely than the other wheats. This lodging resulted in shrinkage

TABLE 2.—*Yield, yard-row, and other data from the Fargo rod-row wheat experiments.*

| Name | Yield in bushels per acre | Lodging, 0–10 | Kernels per spikelet | Fertile spikelets per spike | Sterile spikelets per spike | Mid-kernels per spike | Total kernels per spike | Weight of grain per 50 heads, grams | Stools per plant | Plants per yard | Heads per yard | Weight of grain per yard grams | Weight of 1,000 kernels, grams | Plumpness, 5–1 | Weight per bushel, pounds | Rust |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mindum (durum) | 39.3 | 4 | 1.9 | 12.8 | 2.5 | 2.1 | 24.7 | 37.6 | 3.1 | 44 | 137 | 102.9 | 30.50 | 3 | 57.5 | 0 |
| Marquis | 37.4 | 2 | 1.6 | 12.4 | 2.4 | 0.1 | 19.3 | 28.0 | 2.4 | 73 | 176 | 98.5 | 29.05 | 4 | 60.0 | 8 |
| *albidum* 0721* | 37.4 | 8 | 1.7 | 13.1 | 1.6 | 0.4 | 22.5 | 34.2 | 2.9 | 49 | 142 | 97.0 | 30.40 | 4+ | 59 5 | 9 |
| Reward | 37.0 | 3 | 1.7 | 10.0 | 1.7 | 0.4 | 16 8 | 24.9 | 2.7 | 78 | 211 | 104.9 | 29.55 | 4+ | 62.5 | 1 |
| Kota-Webster H118-25 | 36.8 | 4 | 1.7 | 10.8 | 2.1 | 0.3 | 18.3 | 25.4 | 2.4 | 74 | 179 | 90.9 | 27.75 | 4— | 59.5 | 0 |
| Barnatka (red durum) | 35.8 | 3 | 1.7 | 13.1 | 2.8 | 3.0 | 22.2 | 34.9 | 3.0 | 36 | 109 | 102.0 | 31.50 | 3— | 60.0 | 0 |
| Garnet | 34.9 | 5 | 1.9 | 10.4 | 2.9 | 0.8 | 19.8 | 22.7 | 2.2 | 97 | 216 | 98.2 | 23.00 | 4+ | 59.5 | 1 |
| Marquillo | 32.7 | 3 | 1.7 | 11.0 | 2.0 | 0.5 | 18.9 | 26.4 | 2.6 | 62 | 160 | 84.4 | 27.90 | 3+ | 57.0 | T |
| Ceres | 32.1 | 6 | 2.1 | 12.9 | 2.7 | 4.4 | 26.9 | 37.2 | 2.4 | 47 | 113 | 84.1 | 27.70 | 4— | 56.5 | 0 |
| *albidum* 0604* | 31.5 | 6 | 1.7 | 13.2 | 1.8 | 0.4 | 22 4 | 32.5 | 2.5 | 51 | 126 | 81.8 | 28.95 | 4+ | 58.0 | 14 |
| *lutescens* 062* | 31.3 | 9 | 1.7 | 12.0 | 1.4 | 0.8 | 19.9 | 33.0 | 2.6 | 59 | 156 | 102.8 | 33.10 | 4+ | 59.0 | 4 |
| "Hurdsfield" | 31.0 | 3 | 2.0 | 12.3 | 3.2 | 0.9 | 25.0 | 30.7 | 2.1 | 75 | 156 | 95.8 | 24.55 | 4— | 58.5 | T |
| *milturum* 0321* | 30.9 | 1 | 1.5 | 11.4 | 2.8 | 0.5 | 17.4 | 22.8 | 2.4 | 77 | 188 | 85.8 | 26.25 | 4+ | 58.5 | 50 |
| Marquis-Kanred II-17-37 | 29.7 | 4 | 1.7 | 11.9 | 2.1 | 0.3 | 19.7 | 26.9 | 3.2 | 49 | 157 | 84.5 | 27.35 | 3+ | 56.0 | T |

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1656.44 | 29.4 | 5 | 2.3 | 11.2 | 2.6 | 3.2 | 25.4 | 28.1 | 1 6 | 84 | 137 | 77.1 | 22.10 | 3 | 56.5 | 0 |
| 1656.84 | 28.2 | 7 | 2.3 | 11.1 | 1.9 | 4.7 | 25.7 | 30.7 | 2.1 | 59 | 126 | 77.3 | 23.85 | 3 | 54.0 | 0 |
| 1656.85 | 27.9 | 6 | 2.2 | 11.9 | 2.6 | 4.3 | 26.2 | 30.2 | 1.8 | 76 | 133 | 80.3 | 23.10 | 3 | 56.0 | 0 |
| 1656.48 | 25.8 | 7 | 2.2 | 12.4 | 2.2 | 3.8 | 26.8 | 25.7 | 2.2 | 49 | 110 | 56.6 | 19.20 | 3— | 52.5 | 0 |
| *caesium* 0111* | 25.2 | 7 | 2.0 | 10.2 | 4.8 | 1.6 | 20.3 | 17.8 | 2.9 | 58 | 166 | 59.2 | 17.55 | 2 | 56.5 | T |
| 1656.125 | 24.4 | 5 | 2.2 | 12.0 | 2.5 | 3.4 | 26.7 | 30.3 | 2.0 | 57 | 114 | 69.0 | 22.70 | 4— | 55.0 | 0 |
| Marquis-Emmer H35-24 | 24.1 | 4 | 1.6 | 10.6 | 1.8 | 0.1 | 16.6 | 23.3 | 3.1 | 65 | 202 | 94.1 | 28.05 | 3 | 52.0 | 0 |
| 1656.6 | 23.1 | 3 | 1.9 | 10.8 | 3.0 | 1.4 | 21.4 | 24.0 | 1.9 | 80 | 151 | 72.6 | 22.95 | 4— | 57.0 | 0 |
| Kota | 22.9 | 7 | 2.1 | 10.3 | 3.2 | 3.0 | 22.0 | 24.0 | 2.8 | 83 | 233 | 111.7 | 21.80 | 3— | 53.0 | T |
| Hope | 21.7 | 3 | 1.7 | 10.3 | 3.3 | 0.1 | 18.0 | 19.9 | 3.2 | 66 | 208 | 83.0 | 22.15 | 2+ | 50.5 | 0 |
| 1656.81 | 20.1 | 3 | 2.1 | 11.5 | 2.7 | 3.2 | 24.3 | 24.7 | 2.2 | 57 | 124 | 61.2 | 20.35 | 3 | 51.0 | 0 |
| 1656.10 | 19.2 | 3 | 2.0 | 10.3 | 2.5 | 1.7 | 20.5 | 17.8 | 1.8 | 84 | 149 | 53.1 | 17.35 | 2 | 50.5 | 0 |
| 1656.97 | 16.6 | 6 | 2.1 | 11.9 | 2.4 | 2.1 | 25.1 | 26.4 | 1.7 | 76 | 125 | 66.1 | 21.10 | 2+ | 50.5 | 0 |

*This series is from the U. S. S. R. (Russian) experiment stations and these numbers indicate some of their best sorts.

of kernel, decreasing its weight with a consequent decrease in yield. The 1656 selections, it so happened, had on the average, more kernels per head than the other wheats. In both cases, the correlation coefficients between yield and weight per 1,000 kernels is of a high order, higher at Fargo than at Langdon, because at Fargo an increase in kernel number in many cases failed to help out yield by reason of weak straw. At Langdon, the weight per 1,000 kernels of the 1656 selection and Ceres was greater than for the other common wheats. It is evident that, if at Fargo the kernel weight had been allowed to attain normal, as it evidently did at Langdon, the yields of the 1656 selection would have been much higher. Results comparable to those selections at Langdon might have been expected.

Marquillo and Hope yielded nearly the same at Langdon, but the latter was much lower at Fargo. At Fargo, Marquillo had distinctly fewer kernels per head, but because of comparatively strong straw its kernel weight suffered much less than did the kernel weight of the 1656 selections. But Hope at Fargo, with not much more lodging than Marquillo, suffered much in weight of kernel. The weight of kernels per 1,000 for these two wheats at the two places was as follows:

| | Marquillo | Hope |
|---|---|---|
| Langdon | 36.40 | 35.00 |
| Fargo | 27.90 | 22.15 |

A similar comparison for Ceres, Marquis, and 1656.85 is worth while and is as follows:

| | Marquis | Ceres | 1656.85 |
|---|---|---|---|
| Langdon | 34.05 | 32.60 | 35.35 |
| Fargo | 29.05 | 27.70 | 23.10 |

While the 1656.85 kernel is the heavier at Langdon, it is much the lower at Fargo, as a direct result of the weaker straw. Comparing Marquis and Ceres, one finds almost the same decrease in kernel weight for the two wheats, While the Ceres lodging was put at 6 and Marquis at only 2, these figures do not indicate that the lodging of Ceres had much effect upon kernel weight.

The inherent yielding capacity of these two wheats is a matter of considerable interest, both practically and theoretically. In North Dakota, rust has generally been present when the two have been grown. As shown in the preceding article in this JOURNAL, in the 28 cooperative experiments of 1928 Ceres almost uniformly outyielded Marquis. In the Fargo experiments, Ceres much exceeded Marquis in weight of grain per head. The stooling of the two wheats was the same, but the Marquis stand in the two yards sampled was nearly 60% greater for Marquis. It seems likely that the better stand for

Marquis explains the yield difference in this case, but why this happened is not clear. The rate of seeding of Ceres was slightly higher than for Marquis and the two lots of seed were essentially of the same quality. With an equality of stand, Ceres would be expected to outyield Marquis, although if the stand of Marquis had been thinner, the number of its kernels per head might have been greater.

## COMPARISON OF MEANS

Somewhat closer study is warranted in comparing some of the characters of the two lots of wheat in our attenpt to analyze yield. The Fargo-grown wheats may be divided into two groups, *viz.*, those hybrid selections which have resulted from crossing Marquis and Kota (6), and the other common wheats. This division is somewhat arbitrary, but this group of hybrid selections has certain similar characters of moment. While a single yard sample for one variety can not be shown to be a fair sample, a series of yard samples of a group of wheats averaged together may possess value. The plants per yard of the Marquis-Kota selections, Ceres and nine 1656 selections, to be designated hybrid selections, were averaged as also were the 15 remaining common wheats. As might be expected, the two groups showed nearly the same number of plants in each case, 68 and 67, per yard, respectively. This followed directly from reasonably uniform seeding and germination conditions. The number of fertile culms per plant differed for the two groups, the averages being as follows:

| | |
|---|---|
| Miscellaneous | $2.7 \pm 0.06$ |
| Hybrid selections | $2.0 \pm 0.05$ |
| | $0.7 \pm 0.08$ |

Thus the difference is seen to be highly significant. The hybrid selections showed much less stooling capacity than the other wheats with a consequent defect of 28% of heads per unit of area. Evidently heavier seeding would be in order for these wheats if they usually stooled in this manner.

A different picture is presented with respect to number of kernels per head as indicated by the following means:

| | |
|---|---|
| Hybrid selections | $24.8 \pm 0.47$ |
| Miscellaneous | $19.8 \pm 0.40$ |
| | $5.0 \pm 0.62$ |

This difference is likewise highly significant, but because of shriveled grain, due to lodging in this experiment, the weight of grain per head is essentially the same for the two groups of wheat. The mid-

kernel differences of the two groups account for relatively the major part of the difference between number of kernels per head, although the two basal floret kernels per spikelet calculated to a head basis are very significantly the greater for the hybrid selections.

While the kernels per head are greater for the hybrid selections, the miscellaneous wheats have the greater weight per 1,000 kernels. The two means are:

| | |
|---|---|
| Miscellaneous | $26.53 \pm 0.68$ |
| Hybrid selections | $22.06 \pm 0.57$ |
| | $4.47 \pm 0.89$ |

The difference indicated is very significant. Summarizing, one finds that the lesser stooling capacity of the hybrid selections, combined with their lesser weight per 1,000 kernels, more than offsets the advantage of greater number of kernels per head. The net result is a difference in yield in bushels per acre as follows:

| | |
|---|---|
| Miscellaneous | $31.0 \pm 0.90$ |
| Hybrid selections | $24.7 \pm 1.05$ |
| | $6.3 \pm 1.38$ |

The ratio of error to difference is 4.6, thus indicating a very significant excess of yield of the miscellaneous wheats. It is evident that the weaker straw decreased the yields of the hybrid selections by shrinking the grain. Ceres, with its stronger straw, yielded most among the hybrids. Where lodging is apt to occur, strength of straw is of major importance in considering standards of breeding.

At Langdon, lodging was comparatively slight, doing no evident damage. It is thus possible to continue the comparison of Marquis-Kota hybrid selections and other wheats with one condition quite radically modified, that of lodging. The Langdon wheats included the five selections so closely allied to the Kota variety that their average represents fairly well the Kota parent. Four common wheats, *viz.*, Marquis, Reward, Marquillo, and Hope, form a group united at times with the Kota selections to compare with the hybrid selections. The weights per bushel, even of the weak-strawed Kota-like selections, and the good physical character of the grain were evident tokens of an optimum development of the crop. The moderate average yield of 23.4 bushels may be reasonably explained by the severe spring drought which persisted until into June. The hybrid selections, as at Fargo, exceed the other common wheats in kernels per head. Comparing the four non-Kota wheats with the hybrids, the following difference in kernels per head is secured:

| | |
|---|---|
| Hybrid selections | 29.0±0.76 |
| Four named varieties | 23.2±0.74 |
| | 5.8±1.06 |

When the four named varieties and the five Kota selections are combined, the difference is in favor of the hybrids by 3.8±0.95 kernels. The difference here is significant. Omitting the hybrid selection 1656.6, which yielded poorly in most of the 1928 experiments and which is set off in some respects from the other hybrids, the hybrids have significantly more kernels per head than the Kota selections by 3.1±0.66 kernels. In the Fargo experiment, Kota had a relatively high number of mid-kernels. The Kota-like selections at Langdon are also thus characterized. At Fargo, Marquis had 0.1 mid-kernel per head and 1.3 at Langdon. The three groups at Langdon had the following mid-kernel means:

| | |
|---|---|
| Four miscellaneous | 0.9±0.14 |
| Kota-like selections | 2.9±0.15 |
| Hybrid selections | 4.2±0.30 |

All differences are significant and this is especially pronounced between 2.9 and 0.9. The large number of kernels per head of the hybrids evidently traces back to the Kota parent, and if the mid-kernels of the hybrids significantly exceed those of the Kota parent, which they seem to do, this excess may be due, perhaps, to a better floret fertilizing character inherited from the Marquis parent.

The weight per 1,000 kernels for the three groups is as follows:

| | |
|---|---|
| Four named varieties | 34.75±0.37 |
| Hybrid selections | 33.63±0.63 |
| Kota selections | 30.48±0.27 |

The kernel weight of the hybrids is not significantly less than the kernel weight of the four named varieties, but is significantly more than that of the Kota selections.

In the Langdon wheats stooling varies but little among the three groups, the number of kernels per head is highest with the hybrids and low with the named varieties, while the weights per 1,000 kernels are low for the Kota hybrids and about equal for the two other groups. From this comparatively high yields would be expected from the hybrid selections among the common wheats, and such expectations are fulfilled. The three means of yield are as follows:

| | |
|---|---|
| Hybrid selections | 24.0±0.49 |
| Four named varieties | 20.8±0.45 |
| Kota-like selections | 20.7±0.15 |

The hybrids very significantly out-yield both the named varieties and the Kota selections.

The durum wheats at Langdon yielded well and the reasons are obvious. Bot. 216 decidedly surpassed all common wheats in kernels per head, in weight per 1,000 kernels, and stood high in stooling. This wheat surpasses the next highest recorded yield by 7.6 bushels per acre. Mindum, whose yield was lost, would probably have yielded nearly as much. Bot. 212, with a 1,000-kernel weight of only 32.50 grams, had the maximum kernels per head and stood second in recorded yield. Bot. 211 had high 1,000-kernel weight but low total kernel count per head. Two common wheats surpassed the yield of this wheat.

These yields show clearly enough that at least certain of the durum wheats possess elements of prolificacy greater than those possessed by common spring wheats. Kota seems to possess these elements to a certain degree and they seem to find fuller expression in certain hybrid Kota derivatives. It has been held by some that Kota traces back to durum parentage. The prolific quality of Kota may or may not be accounted for in this manner, but Marquillo, as a durum-common wheat derivative, does not exceed its Marquis parent in prolificacy. This character might perhaps be made available by proper selections within common-durum crosses. This would be following the suggestion made hv Meister (3).

Biffen (1) has suggested that the sparse fruiting, common in most spring wheats, might be remedied by crossing with a certain Chinese wheat bearing four and five kernels per spikelet. This attempt was made by the writer, with very indifferent success. The Chinese wheat had too many characters in defect to make its use possible as a desirable parent. It may be that the Marquis-Kota hybrids, herein described, represent rather marked advances in spike prolificacy, although the spike characters of certain durums indicate that greater advances are yet to be made before spring common wheats equal durums. Whether further advances can be best attained by crossing with durum or with common wheat, has yet to be decided. While no analytical study has been made upon the new variety Reliance derived by crossing Marquis and Kanred, one may anticipate that it is characterized by head prolificacy similar to that of Ceres and its sister selections.

## GENERAL DISCUSSION

Some of the important elements concerned in yield in this discussion, which has not dealt with disease resistance, have been (a) amount of stooling, (b) kernels per head, and (c) weight of 1,000 kernels, either inherent or affected by lodging as a consequence of weak straw. A knowledge of these factors in relation to yield is of

importance when parents are being chosen for the production of high-yielding varieties in connection with disease resistance. As Hope has shown itself essentially immune to stem rust under field conditions, in addition to being nearly free from smut, this variety, with certain sister selections, becomes highly important as parental material, but it is low in kernels per head and is particularly deficient in mid-kernels.

Marquis, while less deficient than Hope in kernels per head, falls behind Kota and still further behind Ceres. The latter variety seems to show an advance in this character over both its parents. Evidently if Hope and Marquis were hybridized, one would not anticipate securing transgressive variations separated from the parent means by differences so great as those that separate Marquis from Ceres and from certain of the 1656 selections. This deficiency in kernels per head would almost certainly not be compensated for in an increased weight per 1,000 kernels. A deficiency in prolificacy, such as is here indicated, would be a liability in a variety which could not be tolerated indefinitely in a well-balanced wheat-breeding program. The same reasoning holds true, of course, with regard to strength of straw, although weak straw is a defect only when lodging occurs. It does not operate continuously as does the defect of limited kernel formation found in Hope and Marquis. Perhaps Marquis has not been recognized as being limited in this manner and receives such recognition only when compared with a variety like Ceres. Results recently secured by Clark and Ausemus (2) from crosses made between Hope and Marquis and Hope and Ceres furnish a certain degree of empirical evidence tending to confirm the ideas here set forth. Families of the $F_3$ generation of these two crosses were grown comparatively with their parents and yields were secured in bushels per acre. The means and probable errors of the parents and $F_3$ hybrids were as follows:

| | Hope x Marquis | Hope x Ceres |
|---|---|---|
| Hope | $26.8 \pm 0.69$ | $23.8 \pm 0.69$ |
| $F_3$ families | $29.0 \pm 0.32$ | $32.2 \pm 0.30$ |
| Marquis or Ceres | $25.9 \pm 1.04$ | $37.9 \pm 1.04$ |

The $F_3$ families of the Hope x Marquis cross are on the horizon of significance in excess of yield to each of the two parents. The difference in yield between the Hope x Marquis and Hope x Ceres $F_3$ families is $3.2 \pm 0.44$ bushels with a Dev. /P.E. ratio of 7.2, indicating a very marked difference. Some of the Hope x Ceres $F_3$ families exceed the maximum Ceres yield. No data are available to show what physical factors are mainly responsible for the differences in yields shown.

It is suggested that Kota has certain factors for prolificacy which are wanting in most hard red spring wheats. These factors find somatic expression in part, in Kota, and in part are inhibited. In Ceres, and in certain of the 1656 selections, these prolificacy factors, inherited from Kota, find freer somatic expression and as a consequence there have resulted wheats more fruitful than Kota and especially more fruitful than ordinary spring wheats. In producing an improved wheat the introduction of this prolific element into any proposed cross is of an importance comparable to the introduction of other characters for yield, for quality, or for disease resistance.

## SUMMARY

An analytical study of wheat varieties for characters affecting yield was made for two localities, Fargo and Langdon, in 1928. These characters in the main were as follows: Kernels per spikelet, number of fertile spikelets, sterile spikelets, mid- and total kernels per head, weight of grain per 50 heads, stooling, number of plants, number of heads and weight of grain per yard, and weight per 1,000 kernels.

At Langdon significant positive correlations were obtained between yield as one variable and fertile spikelets per head, total kernels per head, mid-kernels per head, weight of grain per 50 heads, and weight of 1,000 kernels as the other variables. A significant negative correlation was found between yield and number of sterile spikelets per head.

At Fargo positive correlations were found between yield and fertile spikelets per head, weight of grain per 50 heads, and weight per 1,000 kernels. Negative, but not significant, correlations were found between yield and number of sterile spikelets per head, number of kernels per head, and number of mid-kernels per head.

The yields at Fargo, aside from those of two durums, were divided into two groups, *viz.*, the wheats of one group consisted of certain selections made from a cross between Marquis and Kota, and those of the other group included the remainder. The group of hybrid selections had a significantly less number of fertile culms per plant than did those of the miscellaneous wheats, but a significantly larger number of kernels per head.

At Fargo, because of the greater lodging of the hybrid selections, their weight per 1,000 kernels was significantly less than for the miscellaneous common wheats. This resulted in a significantly lower yield per acre for the hybrid selections.

At Langdon three groups were recognized in addition to four durums, one group consisting of four named varieties, another of five Kota-like selections, and the third of seven of the Marquis x Kota hybrid selections. The hybrid selections exceeded the other common wheats in total kernels per head and in mid-kernels per head. The hybrid selections did not differ significantly from the four named varieties in weight per 1,000 kernels, but exceeded Kota significantly in this respect.

At Langdon the hybrid selections significantly outyielded the group of named varieties and the Kota selections, which excess yield was directly attributable to the greater number of kernels per head plus an equivalence or excess of weight per 1,000 kernels. The durum wheats at Langdon gave high yields, comparatively, due to a combination of many kernels per head and high weight per 1,000 kernels.

In the production of new varieties by breeding, careful attention must be paid to the character of prolificacy, that is, to the number of kernels per head. Most common spring wheats are deficient in this character, but the evidence adduced here indicates that the Marquis x Kota hybrid selections described possess this character to a certain degree. This character, in a more marked form, is possibly obtainable from parents taken from the durum group, but no wheat of such known parentage has been observed to carry this character.

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# THE PRODUCTION OF ARTIFICIAL MANURE FROM OATS STRAW UNDER CONTROL CONDITIONS[1]

P. E. Brown and F. B. Smith[2]

The experiments on the production of artificial manure in England, reported by Hutchinson and Richards (4)[3] several years ago, have led to a number of attempts to devise a practical method for producing an artificial manure from waste materials on American farms. The lack of farm manure frequently prevents a regular supply of this valuable fertilizer for all the land on the farm, and as a result many soils are becoming deficient in organic matter. The straw produced on the farm is of little or no value for application to the soil, and indeed it is considered a waste material and often burned or otherwise destroyed, although it contains much potentially valuable organic matter. To provide a supplement for farm manure, therefore, and to utilize a waste material, the study of the methods of producing artificial manure by composting straw has seemed most desirable practically as well as from the technical standpoint. Experiments in Missouri (1, 2) have shown that the process may be developed on a practical basis. Tests in Oregon (3) have also shown the possibilities of the process and some technical data have been presented.

Work has been under way in Iowa for four years in the attempt to produce a manure which would give similar effects to farmyard manure and which could be made on the farm without difficulty. This work is not yet completed nor have we succeeded in producing an entirely satisfactory material. Experiments are now under way on a more complete basis than those carried on in the past and these field results will be reported on later.

In the course of the studies some tests of the production of artificial manure under control conditions in the greenhouse were carried out to give necessary fundamental information for the field tests. In these studies the rate of decomposition was measured and various chemicals were used with the straw. Other experiments in the laboratory were run to determine the rate of carbon dioxide produotion from the straw mixed with certain nitrogenous materials when tested in sand cultures. Additional greenhouse tests were made tc

[1]Paper read at the annual meeting of the Society held in Washington, D. C., November 23, 1928. Contribution from the Soils Department, Iowa State College, Ames, Iowa.

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[3]Reference by number is to "Literature Cited." p 322.

learn the comparative effects of these artificial manures and farm manure on the nitrate production, the nitrifying power, and the nitrate-assimilating power of a typical Iowa soil. These experiments will be reported here briefly.

SERIES I

In the first test, 2 kg of dry oats straw were mixed with the various nitrogenous materials applied in amounts representing 1% of nitrogen and with calcium carbonate in one case and placed in 4-gallon earthenware jars in the greenhouse. The straw was wet thoroughly and kept moist throughout the incubation period. The moisture content was about 300%, varying somewhat at different dates. Temperature and moisture determinations were made regularly, but the results are not given as the variations were slight and of little significance.

At the end of five months the percentage of the straw decomposed as shown by the amount soluble in 6% hydrogen peroxide, according to the Robinson and Jones method (5), was determined and the nitrate nitrogen by the Kjeldahl method modified to include nitrates. The results are given in Table 1.

The rate of decomposition was the greatest with the ammonium sulfate and calcium carbonate, although the sodium nitrate and urea had only slightly smaller effects. The calcium nitrate and cyanamid showed a rate of decomposition only a little greater than that in the untreated straw.

TABLE 1.—*The rate of decomposition of straw (5 months).*

| Compost No. | Treatment | Decomposed (Robinson and Jones method) % | Nitrogen as nitrate % | Total nitrogen % |
|---|---|---|---|---|
| 1 | Check (no treatment) | 69.2 | 0.42 | 0.99 |
| 2 | 1% N as $(NH_4)_2SO_4$+5% $CaCO_3$ | 80.4 | 0.58 | 2.08 |
| 3 | 1% N as $NaNO_3$ | 78.0 | 0.55 | 2.24 |
| 4 | 1% N as $Ca(NO_3)_2$ | 71.2 | 0.65 | 2.59 |
| 5 | 1% N as Urea | 78.6 | 0.45 | 2.32 |
| 6 | 1% N as $CaCN_2$ | 70.0 | 0.86 | 3.33 |

More nitrogen was present as nitrate in the treated straws, although in the case of the urea treatment there was only a small difference from the check. A greater content of nitrates was found where the cyanamid was used, probably due to the slower decomposition and less nitrate assimilation. The total nitrogen content was of course much greater in the case of all the treated straws. With the am-

monium sulfate and lime there was the lowest amount of nitrogen among all the treated materials, this corresponding to the greatest decomposition. The largest content was found where the cyanamid was used, due probably to the slower decomposition and the smaller loss of nitrates at the end of five months.

The results as a whole indicate that, under control conditions of moisture and temperature, composting oats straw with ammonium sulfate and lime, with sodium nitrate, or with urea may lead to rapid decomposition of the straw with the production of a good artificial manure.

## SERIES II

In the second series, which was also carried out in the greenhouse under control conditions, the plan used in the first series was followed, except that instead of applying the various nitrogenous materials in amounts representing 1% of nitrogen they were used at the rate of 0.75, 0.50, and 0.25% of nitrogen, adding $CaCO_3$ with the ammonium sulfate as in the earlier work. These tests were carried for nine months at the end of which time the same determinations were made as in Series I. The results are given in Table 2.

TABLE 2.—*The rate of decomposition of straw (9 months).*

| Compost No. | Treatment | Decomposed (Robinson and Jones method) % | Nitrogen as nitrate % | Total nitrogen % |
|---|---|---|---|---|
| 1 | Check (no treatment) | 58.5 | 0.46 | 1.12 |
| 2 | 0.75% N as $(NH_4)_2SO_4$+5.0% $CaCO_3$ | 76.3 | 0.76 | 2.51 |
| 3 | 0.50% N as $(NH_4)_2SO_4$+5.0% $CaCO_3$ | 76.0 | 0.78 | 2.41 |
| 4 | 0.25% N as $(NH_4)_2SO_4$+5.0% $CaCO_3$ | 74.8 | 0.64 | 2.27 |
| 5 | 0.75% N as $NaNO_3$ | 69.3 | 0.74 | 2.44 |
| 6 | 0.50% N as $NaNO_3$ | 69.9 | 0.72 | 2.38 |
| 7 | 0.25% N as $NaNO_3$ | 73.3 | 0.65 | 2.52 |
| 8 | 0.75% N as $Ca(NO_3)_2$ | — | 0.39 | 2.54 |
| 9 | 0.50% N as $Ca(NO_3)_2$ | 72.6 | 0.59 | 2.37 |
| 10 | 0.25% N as $Ca(NO_3)_2$ | 67.4 | 0.55 | 2.30 |
| 11 | 0.75% N as urea | 68.0 | 0.52 | 2.40 |
| 12 | 0.50% N as urea | 74.3 | 0.55 | 2.74 |
| 13 | 0.25% N as urea | — | 0.58 | 2.19 |
| 14 | 0.75% N as $CaCN_2$ | 59.3 | 0.58 | 2.83 |
| 15 | 0.50% N as $CaCN_2$ | 61.5 | 0.59 | 2.65 |
| 16 | 0.25% N as $CaCN_2$ | 72.0 | 0.56 | 2.55 |

Again it is evident that all the nitrogenous materials increased the decomposition of the straw. The ammonium sulfate with the lime showed the greatest effect of all the chemicals used, although the differences in one or two cases were not very definite. The largest

amount of the sulfate had the greatest effect, but in the nine months showed a smaller decomposition than that brought about by the 1% addition after five months, as shown in Series I. The smallest amount of sodium nitrate seemed to have more influence than the larger amounts and much less effect than the 1% addition after five months as tested in the earlier series. The smaller amounts of calcium cyanamid and urea also showed more effects than the larger additions, possibly due to less retardation of decomposition. The larger amounts of calcium nitrate were more effective than the smaller.

The nitrate content was the greatest where the ammonium sulfate and lime were used and was the lowest where the urea and cyanamid were employed. The variations in total nitrogen content were not great enough to be significant and no conclusions can be drawn from the results. It is apparent, however, that there may be a rather rapid decomposition of oats straw when treated with such materials as ammonium sulfate and lime with the production of a good artificial manure.

## SERIES III

In Series III, tests were carried out in the laboratory to determine the carbon dioxide produced during the decomposition of the straw.

In this work 10 grams of finely ground oats straw were mixed with 1 kg of pure quartz sand, 1.% additions being made of nitrogen in the form of ammonium sulfate, sodium nitrate, calcium nitrate, urea, cyanamid, and in one case, 2% of nitrogen in sodium nitrate. The mixtures were placed in 2-liter bottles, all treatments being made in duplicate. The moisture content was brought up to the optimum and kept there during the continuance of the experiment. The bottles were set up in an absorption train and connected with an aspirator. One per cent potassium hydroxide was used to collect the carbon dioxide, aspiration being continuous. The carbon dioxide was determined by the double titration method, the determinations being made daily for the first ten days, then every four days, and finally every week until 83 days had elapsed.

The results are not given for the daily determinations, but they are summarized in Table 3 for the 10-, 30-, 62-, and 83-day periods.

At the end of the first ten-day period the ammonium sulfate, calcium nitrate, and urea had stimulated the carbon dioxide production considerably, while the small amount of sodium nitrate had no effect and the cyanamid and the larger amount of sodium nitrate depressed the decomposition considerably. The average per day was the greatest with the ammonium sulfate and urea treatments. After 30 days, the greatest total carbon dioxide was again produced

TABLE 3.—*The production of $CO_2$ in mg from decomposing oats straw.*

| Culture No. | Treatment | Total $CO_2$ first 10 days | Average per day | Total $CO_2$ 30 days | Average per day, first 30 days | Total $CO_2$ 62 days | Average per day, 62 days | Total $CO_2$ 83 days | Average per day, 83 days |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Check | 2,098 | 209.8 | 4,841 | 161.3 | 7,307 | 117.8 | 8,570 | 103.2 |
| 2 | Check | 2,087 | 208.7 | 5,009 | 166.9 | 7,451 | 120.1 | 9,179 | 110.5 |
| 3 | 1% N as $(NH_4)_2SO_4$ | 2,883 | 288.3 | 6,209 | 206.9 | 8,607 | 138.8 | 9,850 | 118.5 |
| 4 | 1% N as $(NH_4)_2SO_4$ | 2,988 | 298.8 | 6,505 | 216.8 | 9,236 | 148.9 | 10,660 | 128.4 |
| 5 | 1% N as $NaNO_3$ | 2,133 | 213.3 | 5,505 | 183.5 | 8,676 | 139.9 | 10,055 | 121.1 |
| 6 | 1% N as $NaNO_3$ | 2,095 | 209.5 | 5,541 | 184.7 | 8,336 | 134.4 | 9,734 | 117.2 |
| 7 | 1% N as $Ca(NO_3)_2$ | 2,245 | 224.5 | 4,887 | 162.9 | 7,012 | 113.0 | 8,307 | 100.0 |
| 8 | 1% N as $Ca(NO_3)_2$ | 2,323 | 232.3 | 5,648 | 188.2 | 8,480 | 136.9 | 9,835 | 118.4 |
| 9 | 1% N as urea | 3,101 | 310.1 | 6,650 | 221.6 | 10,020 | 161.6 | 11,466 | 138.0 |
| 10 | 1% N as urea | 2,776 | 277.6 | 5,872 | 195.7 | 8,554 | 137.9 | 9,662 | 116.4 |
| 11 | 1% N as $CaCN_2$ | 1,034 | 103.4 | 3,644 | 126.4 | 6,159 | 99.3 | 7,423 | 89.4 |
| 12 | 1% N as $CaCN_2$ | 850 | 85.0 | 3,454 | 115.1 | 6,109 | 98.5 | 7,311 | 88.0 |
| 13 | 2% N as $NaNO_3$ | 1,343 | 134.3 | 4,343 | 144.7 | 6,762 | 109.0 | 7,939 | 95.6 |
| 14 | 2% N as $NaNO_3$ | 1,682 | 168.2 | 5,068 | 168.9 | 7,709 | 108.2 | 8,978 | 108.1 |

where the ammonium sulfate and urea were employed. The depression from the cyanamid was still evident, but with the larger addition of sodium nitrate there was only a slight depression. The average production per day was much the greatest with the ammonium sulfate and the urea, in the latter case some undoubtedly being formed through hydrolysis.

At the end of 62 days the relationships were practically identical, the cyanamid still showing a depressive effect, while the sodium nitrate in the greater amount had still no stimulative influence. After 83 days similar relations were noted, except that the smaller amount of sodium nitrate and the calcium nitrate showed more stimulative effects. The cyanamid treatment still depressed the carbon dioxide production below that in the untreated check and the ammonium sulfate and urea showed the greatest influence. The average per day for the 83-day period was slightly greater for the urea than for the ammonium sulfate, but the difference was not great, the smaller addition of sodium nitrate being slightly less and the calcium nitrate still less, while the other treatments were lower than the check.

These results showed quite definitely the effect of ammonium sulfate and urea in stimulating the decomposition of oats straw under control conditions. The effects of cyanamid seemed not to be beneficial, but rather to depress the rate of decomposition as measured by carbon dioxide production. The other nitrogenous materials had less effect than the ammonium sulfate or urea.

SERIES IV

Series IV was carried out under field conditions. On August 1, 1927, 1 ton of dry oats straw was treated with 150 pounds of Adco and wet thoroly in the following way: About 1 foot of the dry straw was placed on the ground in a pile 10 feet square and wet thoroughly with water. This was packed down and 25 pounds of the Adco sprinkled over the surface. The process was repeated until the entire ton of straw was treated. The compost was kept moist for three weeks when it was forked over, wet, and packed down. Another ton of straw was treated similarly with a mixture called the "Iowa reagent" which consisted of 67.5 pounds of ammonium sulfate and 100 pounds of limestone. Other mixtures consisted of untreated straw; straw with green sweet clover hay in the proportion of 4 to 1 or 3 to 2; the straw and sweet clover (4 to 1) with the ammonium sulfate and limestone; the 4 to 1 mixture with Adco; and a mixture of 1,000 pounds of cornstalks with the Missouri formula, consisting of ammonium sulfate, 15 pounds of superphosphate, and 40 pounds of limestone.

On May 12, 1928, all the mixtures were tested for percentage decomposition, using the same method as employed in Series I and II, and for nitrate content and total nitrogen The results are given in Table 4.

The addition of the Adco, the mixing of oats straw and sweet clover, and in fact all the treatments of the straw, except the mixture of 1,200 pounds of oats straw and 800 pounds of sweet clover, brought about an increase in the rate of decomposition. In nitrate nitrogen the compost where Adco and straw were used was the lowest, while where the Adco was applied with straw and sweet clover the content was much greater. With the exception of this latter mixture and the treatment with ammonium sulfate and lime, there was less nitrate nitrogen in all the mixtures than in the straw composted alone. The total nitrogen content was the greatest with the ammonium sulfate and lime, with the oats straw and clover (1,200 to 800), and with the straw and clover (1,600 to 400) and Adco mixture. There seemed to be no relation between the total nitrogen content and the rate of decomposition, nor did the nitrate content show the extent of decomposition probably due to changes in the amounts of nitrate nitrogen assimilated.

TABLE 4.—*The decomposition of straw and straw mixtures in the open.*

| Comp-post No. | Treatment | Decomposed (Robinson and Jones method) % | Nitrate nitrogen % | Total nitrogen % |
|---|---|---|---|---|
| 1 | 1 ton oats straw | 73.8 | 0.72 | 1.12 |
| 2 | 1 ton oats straw + 150 pounds Adco | 80.0 | 0.55 | 1.81 |
| 3 | 1 ton oats straw + 67.5 pounds $(NH_4)_2SO_4$ + 100 pounds limestone | 76.8 | 0.78 | 3.00 |
| 4 | 1,600 pounds oats straw + 400 pounds sweet clover | 79.4 | 0.65 | 2.48 |
| 5 | 1,200 pounds oats straw + 800 pounds sweet clover | 73.0 | 0.64 | 3.21 |
| 6 | 1,600 pounds oats straw + 400 pounds sweet clover + 67.5 pounds $(NH_4)_2SO_4$ + 100 pounds limestone | 76.6 | 0.65 | 2.98 |
| 7 | 1,600 pounds oats straw + 400 pounds sweet clover + 150 pounds Adco | 76.5 | 0.74 | 3.20 |
| 8 | 1,000 pounds corn stalks + 45 pounds $(NH_4)_2SO_4$ + 15 pounds superphosphate + 40 pounds limestone | 79.5 | 0.68 | 1.73 |

## SERIES V

The effects of artificial manure produced from oats straw in the greenhouse as described in Series I were tested by applying the various manures to virgin Carrington loam in pots in the greenhouse. Farm manure was applied at the rate of 8 tons per acre and the different artificial manures and the oats straw were added on an equivalent nitrogen basis. The artificial manures consisted of oats straw composted for five months under control conditions of moisture and temperature with treatments as follows:

1. Nothing
2. With 1% N as $(NH_4)_2SO_4 + 5\%$ $CaCO_3$
3. With 1% N as $NaNO_3$
4. With 1% N as $Ca(NO_3)_2$
5. With 1% N as Urea
6. With 1% N as $CaCN_2$

The pots were kept fallow and samples were taken at regular intervals for analysis. The nitrate nitrogen content was determined colorimetrically by the phenoldisulfonic acid method. At three samplings the nitrifying power of the soils was determined, using two methods, one with the soils' own nitrogen and the other with 31.2 mgm of nitrogen as ammonium sulfate and 210 mgm of calcium carbonate per 100 grams of soil, and incubated four weeks at room temperature. At two samplings the nitrate assimilating power of the soils was determined with the addition of 11.1 mgm of nitrogen as potassium nitrate and incubated four weeks.

### NITRATE PRODUCTION

The effects of the artificial manures, the farm manure, and the oats straw on nitrate production in the soils are given in Table 5, determinations being made seven times during the period of the study. The farm manure and straw alone depressed the nitrate content at the first date and one or two of the composts also gave a depression, notably the straw composted alone (No. 1). At the second date, however, the farm manure gave a large increase, while all the artificial manures brought about a depression, the straw alone reducing the nitrate content to a trace. At the third date, all of the artificial manures stimulated the nitrate content, several of them having more effect than the farm manure. At the next three samplings the relative results were similar, but the amounts of nitrate present were much greater. In several instances one or more of the artificial manures surpassed the farm manure in effect on nitrates. At the fourth date of sampling the depressing effect of the straw had disappeared and there was some nitrate present, the amount increasing at the later sam-

TABLE 5.—*Effect of artificial manure on nitrate production in the soil.*

| Soil No. | Treatment | Mgms of nitrate nitrogen per 100 grams dry soil | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | March 19 | April 2 | April 9 | April 23 | April 30 | May 14 | June 15 | Average |
| 1 | Check | 3.07 | 1.56 | 1.35 | 2.46 | 2.62 | 3.28 | 4.20 | 2.65 |
| 2 | Farm manure | 1.42 | 3.51 | 2.37 | 4.45 | 4.00 | 3.87 | 4.15 | 3.39 |
| 3 | Artificial manure No. 2 | 3.03 | 2.28 | 3.49 | 4.52 | 5.51 | 4.38 | 4.50 | 3.96 |
| 4 | Artificial manure No. 3 | 2.73 | 2.16 | 2.99 | 3.65 | 3.08 | 3.94 | 3.70 | 3.17 |
| 5 | Artificial manure No. 4 | 2.85 | 2.17 | 3.12 | 3.19 | 4.68 | 3.70 | 4.10 | 3.40 |
| 6 | Artificial manure No. 5 | 3.01 | 2.14 | 1.89 | 2.78 | 4.30 | 3.92 | 4.10 | 3.16 |
| 7 | Artificial manure No. 6 | 2.98 | 2.33 | 2.47 | 3.52 | 4.15 | 3.70 | 4.85 | 3.42 |
| 8 | Artificial manure No. 1 | 2.58 | 2.42 | 2.86 | 3.25 | 4.93 | 3.70 | 4.15 | 3.41 |
| 9 | Dry oats straw | Trace | Trace | Trace | 1.00 | 1.03 | 1.80 | 3.20 | 1.00 |

plings. At the last sampling the check soil was about as high as any of the treatments, being surpassed slightly by only two, while in one case there was a smaller nitrate content.

The average figures for the seven samplings indicate a very similar effect on nitrate production of all the artificial manures to that of farm manure. Mixture No. 2 had a greater effect and Nos. 3 and 5 had a smaller effect, but all the manures showed an increase over the untreated soil, while the straw alone showed a depression. This, however, would probably have disappeared had the tests been carried over a longer period.

### NITRIFICATION TESTS

The nitrifying power of the soil as affected by the treatments with the various artificial manures was tested at three samplings. The results are given in Table 6. With the soils' own nitrogen and no addition, the farm manure had the greatest effect at the first sampling. All the artificial manures stimulated the nitrifying power, the differences between the various materials being rather slight. At the second date compost No. 6 (with cyanamid) had a slightly greater effect than the farm manure, all the other composts showing a smaller effect but giving an increase over the untreated soils. The straw (untreated) depressed the nitrifying power of the soil at the first date, but began to show an effect at the second sampling and at the third date the soil had recovered from the depression.

TABLE 6.—*Effect of artificial manures on the nitrifying power of the soil.*

| Soil No. | Treatment | Mgms of nitrate nitrogen per 100 grams dry soil | | | | | |
|---|---|---|---|---|---|---|---|
| | | Incubated with soils' own nitrogen | | | Incubated with 31.2 mgms N as $(NH_4)_2SO_4$ +210 mgms $CaCO_3$ | | |
| | | March 19 | May 14 | June 15 | March 19 | May 14 | June 15 |
| 1 | Check | 1.56 | 3.43 | 5.76 | 28.50 | 30.90 | 22.50 |
| 2 | Farm manure | 3.51 | 5.33 | 5.90 | 35.30 | 35.30 | 26.45 |
| 3 | Artificial manure No. 2 | 2.28 | 4.64 | 5.67 | 31.55 | 31.90 | 32.00 |
| 4 | Artificial manure No. 3 | 2.16 | 4.79 | 6.00 | 32.25 | 34.90 | 28.75 |
| 5 | Artificial manure No. 4 | 2.17 | 3.85 | 5.56 | 31.42 | 29.10 | 36.32 |
| 6 | Artificial manure No. 5 | 2.14 | 4.28 | 6.20 | 29.90 | 35.70 | 30.25 |
| 7 | Artificial manure No. 6 | 2.33 | 5.55 | 5.94 | 22.10 | 33.15 | 26.10 |
| 8 | Artificial manure No. 1 | 2.42 | 4.50 | 6.00 | 31.30 | 36.60 | 28.35 |
| 9 | Dry oats straw | Trace | 2.83 | 5.56 | 26.55 | 29.30 | 29.00 |

At the third sampling several of the treatments showed more effect than the farm manure, but the differences were not large. In two cases the artificial manures did not increase the nitrifying power but showed instead a slight depression.

When the nitrifying power tests were carried out using ammonium sulfate and calcium carbonate, the farm manure again showed the greatest stimulation at the first sampling. The straw alone and the artificial manure No. 6 (with cyanamid) depressed the nitrifying power. The other artificial manures showed a stimulation. At the second sampling the straw alone showed a slight depression and artificial manure No. 4 was lower than the check, but all the others gave a stimulation, Nos. 1 and 5 being as effective as the farm manure. At the third sampling all the materials gave a stimulation, No. 4 showing the greatest effect and farm manure and No. 6 giving the least influence. The depressing effect of the straw had apparently disappeared at the time of this sampling.

These results as a whole indicate that the artificial manures produced as described may not have quite as great an effect as farm manure when first applied, but after a short time the stimulative influence on the nitrifying power may be greater. The results hardly permit a choice among the several mixtures, but that with cyanamid seemed slower to bring about a stimulation.

## NITRATE ASSIMILATION

The nitrate assimilation tests were carried on with the addition of potassium nitrate. The results appear in Table 7. At the first sampling the farm manure showed less effect than the check, while all the artificial manures, except No. 4, stimulated the nitrate assimilation or had no effect. The straw alone reduced the assimilation. At the second sampling some stimulation was shown by several of the artificial manures. The oats straw and manure depressed the assimilating

TABLE 7.—*Effect of artificial manures on nitrate assimilation.*

| Soil No. | Treatment | Mgms of nitrate nitrogen per 100 grams dry soil: Soil alone, May 14 | Soil alone, June 15 | Soil incubated with 11.1 mgms N as $KNO_3$, May 14 | Soil incubated with 11.1 mgms N as $KNO_3$, June 15 | Mgms of nitrate nitrogen assimilated per 100 grams dry soil, May 14 | June 15 |
|---|---|---|---|---|---|---|---|
| 1 | Check | 3.4 | 4.5 | 11.9 | 14.7 | 2.6 | 0.9 |
| 2 | Farm manure | 5.3 | 4.7 | 14.5 | 16.3 | 1.8 | —0.5 |
| 3 | Artificial manure No. 2 | 4.6 | 5.0 | 13.2 | 15.1 | 2.5 | 1.0 |
| 4 | Artificial manure No. 3 | 4.8 | 3.6 | 12.5 | 15.1 | 3.4 | —0.4 |
| 5 | Artificial manure No. 4 | 3.6 | 4.8 | 13.4 | 15.8 | 1.3 | 0.0 |
| 6 | Artificial manure No. 5 | 4.2 | 4.1 | 12.3 | 14.1 | 3.0 | 1.0 |
| 7 | Artificial manure No. 6 | 5.1 | 6.2 | 12.7 | 15.5 | 3.4 | 1.7 |
| 8 | Artificial manure No. 1 | 4.5 | 4.9 | 12.6 | 14.0 | 2.9 | 1.0 |
| 9 | Dry oats straw | 2.8 | 4.0 | 12.3 | 15.9 | 1.6 | —0.8 |

power. The results are not very definite, but there are indications of a stimulation in nitrate assimilating power from the use of the various artificial manures. The method employed in this work is still under investigation, and it is hoped that a method may be developed later which will show more definitely and accurately the nitrate assimilating power of a soil.

## CONCLUSIONS

The data secured in these experiments showed that:

1. Composting oats straw with ammonium sulfate and lime, with sodium nitrate, or with urea under conditions in the greenhouse for five months led to rapid decomposition.

2. The application to the straw of 1% or less of nitrogen in the form of various nitrogenous materials permitted of the production of a good artificial manure after five to nine months' composting under optimum moisture and temperature conditions. With additions smaller than 1% the treatment with ammonium sulfate and lime seemed to be preferable.

3. The rate of decomposition of various mixtures of straw and chemicals in sand as measured by carbon dioxide production in the laboratory was very rapid when ammonium sulfate with calcium carbonate or urea were employed. The other nitrogenous materials were less effective and cyanamid gave a depression.

4. The results of a field experiment indicate that decomposition was more rapid in various compost mixtures than with straw alone. The decomposition in the open, however, was not so rapid as in the greenhouse and there were no great differences among the different composts.

5. The artificial manures produced in the greenhouse with two exceptions showed as great or greater effect than farm manure on the nitrate content of a virgin Carrington loam. The nitrifying power of the soil was stimulated by practically all of the mixtures; but to a less extent than by manure in the early days following treatment, although later the effects were greater than those brought about by manure. In some cases the nitrate assimilating power of the soil was stimulated by the artificial manures but not to a large extent. The effects, however, were very similar to those brought about by farmyard manure.

6. The production of an artificial manure which will have similar beneficial effects to farm manure seems quite possible.

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# RELATIVE RATES OF DECOMPOSITION OF CORN AND KAFIR STUBBLE[1]

P. L. Gainey[2]

For a number of years the Kansas Agricultural Experiment Station has been investigating various phases of the injurious residual effect that a crop of sorghum exerts upon the succeeding crop. Such an injurious effect has long been recognized. In Kansas, where more than 1,000,000 acres are annually grown to sorghums, and where a depression in yield of wheat following sorghum was found by Sewell (5)[3] to be 3 bushels per acre (Table 1) compared with wheat following corn, such injury assumes considerable economic importance. The injury reported by Sewell under Kansas conditions, however, does not compare with the corresponding decreases in yield following sorghums in the Imperial Valley of California, if the variations in yield evident in the data submitted by Conrad (2) are to be interpreted as due to this factor.

Table 1.—*Yields of winter wheat grown after corn and kafir crops, 1916–21, Manhattan, Kansas.*

| Year | Corn soil: Grain in bushels per acre | Corn soil: Straw in pounds per acre | Kafir soil: Grain in bushels per acre | Kafir soil: Straw in pounds per acre |
|---|---|---|---|---|
| 1916 | 27.8 | —— | 20.3 | —— |
| 1917 | 15.2 | 1,985 | 17.3 | 2,570 |
| 1918 | 13.9 | 2,425 | 8.2 | 2,082 |
| 1919 | 34.0 | 2,049 | 31.1 | 1,872 |
| 1920 | 12.3 | —— | 10.5 | —— |
| 1921 | 5.2 | 750 | 3.6 | 710 |
| Average | 18.1 | 1,802* | 15.1 | 1,809* |

*Average of four years.

A close scrutiny of Conrad's data, however, shows that in no instance is a direct comparison made between the residual effect of a sorghum and any other crop. The nearest approach to such a condition would be in plat A, barley following barley, compared with plat I, barley following milo, and plat B, wheat following wheat, compared with plat D, wheat following milo, a summer fallow intervening in each instance. Yet, in both instances, the yields following milo

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[2]Soil Bacteriologist.

[3]Reference by number is to "Literature Cited," p. 343.

exceeded the yields following the same crop. Where moisture is such an important factor in yields of these crops as it is under Kansas conditions, it would certainly be unfair to attribute the difference in yields of wheat or barley immediately following summer fallow and following milo, as has been done by Conrad, to a specific injurious effect of the sorghum. It is not meant by this criticism of Conrad's data to minimize the deleterious effect that sorghums may have upon the succeeding crop. In Texas, Kansas, and Oklahoma, however, the sorghums are entirely too valuable as forage and grain crops to have their use placed in jeopardy by attributing to them several times the injurious residual effect that they actually have.

Sewell was the first to report upon extensive investigations into the cause of this harmful effect. More recently, Breazeale (1), Conrad (2), and Wilson and Wilson (6) have reported investigations dealing with various phases of the problem. The experiments to be reported in this paper have been pursued intermittently for the past five years, and while they have not dealt directly with sorghum injury, they were undertaken as one phase of this general problem in the hope that they might throw light upon this important question. The recent appearance of the paper by Wilson and Wilson (6) almost renders the publication of these data unnecessary, since they cover almost exactly the same field. However, in some respects the data to be submitted are more extensive, and since they were secured under different conditions, yet in the main agree with the data of Wilson and Wilson, it is hoped they will add weight to and tend to substantiate conclusions drawn by these investigators, thereby justifying publication.

## METHODS EMPLOYED

There are various ways by which information relative to the rate of decomposition of organic substances added to soil may be gained. Probably the most accurate method is to add known quantities of the material in question and then to measure quantitatively that remaining in the soil after varying intervals of time. Where one is dealing with a definite chemical compound, for example dextrose, such a procedure might easily be possible. But where such a heterogeneous complex of compounds as go to make up corn and kafir stubble are being dealt with, obviously this method is out of the question.

Another procedure sometimes employed is to make quantitative determinations of the total organic carbon in the soil immediately after the addition of the substance in question and after varying intervals. A serious criticism leveled against this method is that

there is no way of distinguishing between $CO_2$ formed from the combustion of the unaltered residue and that from various decomposition or synthetic compounds derived from the original organic material.

A third method, perhaps more frequently employed, is to measure certain intermediate or end products formed in the decomposition of the organic material. If the substance is high in nitrogen the amino acid, ammonia, or nitrate nitrogen may be measured. If the substance added is primarily carbonaceous, then the carbon dioxide formed therefrom may be determined.

This latter principle has been employed in the present investigation, and because of the carbonaceous nature of the materials being studied the $CO_2$ evolved has been taken as a measure of the rate of decomposition. The technic employed has been essentially that described previously (3). Perhaps no one realizes better than the writer the numerous criticisms that may be directed against employing methods of measuring the rate of decomposition based upon this latter principle. Yet the advantages of such methods seem to compare favorably with methods based upon any other principle when dealing with materials such as those being studied. Because of the numerous sources of error that may arise in measuring the $CO_2$ evolved over a long period of time, little significance is attached to minor differences.

During the course of these investigations three different batches of corn and kafir materials have been studied. That designated as "A" was collected immediately after harvest by digging up the stubble to a depth of a foot and washing off the adhering soil. Only the larger roots extending perhaps a foot in all directions, the crown, and such of the stalk as would be left in ordinary methods of harvest were included. The materials designated as "B" were secured in a similar manner as "A", except that collection was made in early spring before the ground had warmed sufficiently to speed up micro-organic activity. The material labeled "C" was secured by carefully washing the dirt from large cylinders in which corn and kafir were grown to maturity and recovering as far as possible all roots. In two instances the material was composed primarily of the crown and stalk remaining after harvest, while in the third instance only roots were present.

The stubble was pounded, not ground, into small bits in an iron mortar, the object being to get the material into such a condition that it would be fairly uniformly distributed in the soil yet altered from natural conditions as little as possible. Two per cent of this dried material was added to fresh soil, usually the equivalent of 800

grams of dry soil being used. The moisture content was then brought to as high a point as practicable without danger of puddling in subsequent mixing. In some instances the moisture content of the fresh soil approached this condition so nearly that no further water was added. The moisture content was usually very close to one-half saturation.

The soil was placed in large calcium chloride cylinders, triplicate samples always being prepared. These were connected in series with a $CO_2$ absorption tower between, as illustrated in the publication already referred to, except that the ammonia wash bottles were omitted. Air was drawn through the chain of cylinders all day and the vacuum tank evacuated late in the afternoon, thereby insuring a current of air passing through the system most of the night.

During the early stages of incubation, the $CO_2$ evolved was measured at short intervals, usually daily, but as incubation progressed and the quantity of $CO_2$ daily given off became smaller, the intervals between measurements were lengthened. The quantities of $CO_2$ were determined by diluting to a definite volume the NaOH in the absorption tower and wash bottle and titrating an aliquot, $CO_2$-free water being used and control titration always run.

All calculations have been corrected to 800 grams of soil or 16 grams of plant material in order that the data may be compared without alteration.

## RESULTS

### RELATIVE RATES OF DECOMPOSITION OF CORN AND KAFIR RESIDUES

As previously mentioned, the evolution of $CO_2$ has been taken as the criterion by which to judge the rates of decomposition. Data relative to the evolution of $CO_2$ from soil to which corn and kafir residues were added are contained in Tables 2 to 8, inclusive, and are shown graphically in Figs. 1 to 7, inclusive.

Controls to which no plant residues were added were not included and for this reason the data may be open to criticism. It is true, of course, that an appreciable portion of the $CO_2$ recorded in all tables came from the soil's store of organic matter and not from the organic material added. If interest had been primarily in the absolute rates of decomposition, it would have been essential that checks be run with each experiment. However, only relative rates of decomposition were to be compared in these experiments. Since the soil for each of the six cylinders in any particular experiment came from the same thoroughly mixed batch, differences in the data secured from cylinders containing corn and kafir residues can be as correctly attributed to

the materials added as could such differences had a uniform control factor been subtracted from each. Moreover, the presence of a foreign organic material of any kind may so alter the chemical, physical, and biological conditions existing in a soil that the decomposition of the soil's original organic matter may be materially altered, under which condition there would be no assurance that the $CO_2$ evolved from checks represented accurately that evolved from the original organic material in the soil. Furthermore, six cylinders were as many as could be conveniently handled with the available facilities and it was felt that comparisons should certainly be made in triplicate.

To give some indication of the rate of $CO_2$ evolved from a soil to which no organic material was added, one comparison has been included in Fig. 4. Direct comparisons between the evolution of $CO_2$ in two separate experiments are probably not justified because there is no assurance that the conditions existing in any two experiments were identical, though an effort was made to make the conditions in all the experiments as comparable as possible. Three batches of plant materials were used and since they varied somewhat they will be treated separately.

### RESIDUES "A"

This material was collected a few days after harvest and probably before appreciable decomposition had set in. However, being annual plants, the time of harvest relative to the stage of maturity would probably influence materially the speed of decomposition following harvest. If the plants had reached that stage of maturity where root cells had begun to die, the decomposition of soluble organic materials would already have begun if other conditions, especially moisture, were favorable. In this climate there is a tendency for sorghums to initiate growth from the crown after harvest, provided this precedes frost, whereas there is no such tendency on the part of the corn plant. This would indicate that the corn root cells probably die quicker than do those of kafir. The material in question was collected following regular harvest, no attention being paid to the stages of maturity as it was desired to have material such as would be encountered under practical field conditions.

The data secured from the "A" materials are contained in Tables 2 and 3 and are shown graphically in Figs. 1 and 2.

TABLE 2.—*Decomposition of corn and kafir residues "A" and soil B.*

| Treatment and cylinder No. | Grams of $CO_2$ evolved from 670 grams of soil+16 grams of organic material* Feb. 24 1 day | Feb. 25 1 day | Feb. 27 2 days | March 1 3 days | March 5 4 days | Total 11 days |
|---|---|---|---|---|---|---|
| Corn (2) | 0.977 | 0.737 | 0.682 | 0.822 | 0.561 | 3.779 |
| Corn (4) | 0.833 | 0.759 | 0.671 | 0.698 | 0.615 | 3.576 |
| Average | 0.905 | 0.748 | 0.677 | 0.760 | 0.588 | 3.678 |
| Daily average | 0.905 | 0.748 | 0.339 | 0.253 | 0.147 | —— |
| Kafir (1) | 1.142 | 0.770 | 0.825 | 0.822 | 0.746 | 4.305 |
| Kafir (3) | 1.049 | 0.880 | 0.770 | 0.932 | 0.739 | 4.370 |
| Kafir (5) | 0.983 | 0.877 | 0.660 | 0.858 | 0.720 | 4.098 |
| Average | 1.058 | 0.842 | 0.752 | 0.871 | 0.735 | 4.258 |
| Daily average | 1.058 | 0.842 | 0.376 | 0.290 | 0.184 | —— |

*Experiment (526) started Feb. 23, 1928, 670 grams of soil B+16 grams of organic material "A"+130 cc water (slightly less than one-half saturated). Through error 16 grams of organic material were added to 800 grams of moist soil instead of the equivalent of 800 grams of dry soil. Correction for 800 grams of soil could not be made, since the ratio of organic material and soil would be different.

The two experiments, one running 11 and the other for 45 days, gave quite similar results. The data indicate a slightly more rapid decomposition of kafir residue than of corn.

RESIDUES "B"

These materials were collected in early spring after all cells had been dead for some time, and hence it would be expected that much of the soluble matter would have diffused out. Because of the low temperature prevalent throughout the winter, the more resistant portions of the stubble probably would not have undergone much change.

The data secured from an experiment carried out with these materials are contained in Table 4 and are shown graphically in Fig. 3.

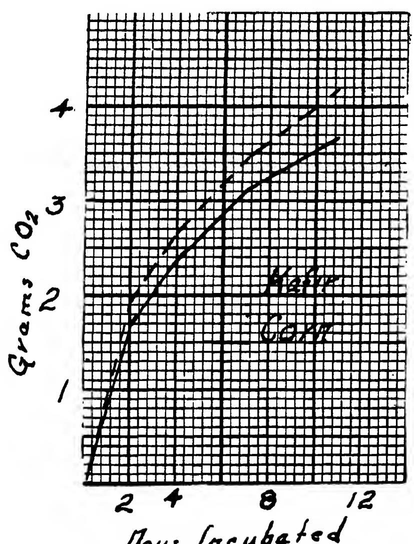


FIG. 1.—Evolution of $CO_2$ from corn (——) and kafir (------), residues "A". From data in Table 2.

TABLE 3.—*Decomposition of corn and kafir residues "A" in soil B.*

| Treatment and cylinder No. | Grams of $CO_2$ evolved from 800 grams of soil+16 grams of organic material* | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mch. 10 | Mch. 11 | Mch. 12 | Mch. 14 | Mch. 17 | Mch. 20 | Mch. 24 | Mch. 29 | Apr. 4 | Apr. 12 | Apr. 23 | Total |
| | 1 day | 1 day | 1 day | 2 days | 3 days | 3 days | 4 days | 5 days | 6 days | 8 days | 11 days | 45 days |
| Corn (2) | 1.287 | 0.770 | 0.385 | 0.440 | 0.352 | 0.286 | 0.506 | 0.594 | 0.814 | 0.814 | 1.122 | 7.370 |
| Corn (4) | 1.122 | 0.748 | 0.407 | 0.484 | 0.352 | 0.319 | 0.506 | 0.605 | 0.946 | 0.869 | 0.902 | 7.260 |
| Corn (6) | 1.067 | 0.715 | 0.418 | 0.495 | 0.341 | 0.363 | 0.506 | 0.495 | 0.671 | 0.682 | 0.891 | 6.644 |
| Average | 1.159 | 0.744 | 0.403 | 0.473 | 0.348 | 0.323 | 0.506 | 0.565 | 0.810 | 0.788 | 0.972 | 7.091 |
| Daily average | 1.159 | 0.744 | 0.403 | 0.237 | 0.116 | 0.108 | 0.126 | 0.113 | 0.135 | 0.099 | 0.098 | —— |
| Kafir (1) | 1.012 | 0.737 | 0.440 | 0.517 | 0.473 | 0.396 | 0.682 | 0.671 | 1.133 | 0.836 | 1.331 | 8.228 |
| Kafir (3) | 1.221 | 0.836 | 0.473 | 0.627 | 0.572 | 0.440 | 0.682 | 0.671 | 1.034 | 0.979 | 1.199 | 8.734 |
| Kafir (5) | 1.155 | 0.836 | 0.506 | 0.627 | 0.517 | 0.374 | 0.627 | 0.616 | 0.814 | 0.836 | 1.089 | 7.997 |
| Average | 1.129 | 0.803 | 0.473 | 0.590 | 0.521 | 0.403 | 0.664 | 0.653 | 0.994 | 0.884 | 1.206 | 8.320 |
| Daily average | 1.129 | 0.803 | 0.473 | 0.295 | 0.174 | 0.134 | 0.166 | 0.131 | 0.166 | 0.111 | 0.110 | —— |

*Experiment (528) started March 9, 1928, 800 grams of soil B+280 cc water (one-half saturated)+16 grams of organic material "A".

TABLE 4.—*Decomposition of corn and kafir residues "B" in soil A.*

| Treatment and cylinder No. | Grams of $CO_2$ evolved from 800 grams of soil+16 grams of organic material* | | | | | | | | $NO_3$ in p.p.m. |
|---|---|---|---|---|---|---|---|---|---|
| | Mch. 5 | Mch. 7 | Mch. 11 | Mch. 19 | Mch. 29 | Apr. 11 | May 12 | Total | |
| | 2 days | 2 days | 4 days | 8 days | 10 days | 13 days | 31 days | 70 days | 70 days |
| Corn (1) | 0.542 | 0.477 | 0.503 | 0.912 | 1.245 | 1.760 | 2.099 | 7.538 | 18.3 |
| Corn (3) | 0.610 | 0.465 | 0.503 | 0.886 | 1.275 | 1.835 | 2.193 | 7.767 | 23.9 |
| Corn (5) | 0.616 | 0.472 | 0.497 | 0.912 | 1.226 | 1.835 | 2.520 | 8.078 | 24.6 |
| Average | 0.589 | 0.471 | 0.501 | 0.903 | 1.249 | 1.810 | 2.271 | 7.794 | 22.3 |
| Daily average | 0.295 | 0.236 | 0.125 | 0.113 | 0.125 | 0.139 | 0.073 | —— | —— |
| Kafir (2) | 1.219 | 0.503 | 0.541 | 0.912 | 1.188 | 1.735 | 1.873 | 7.971 | 67.7 |
| Kafir (4) | 1.232 | 0.522 | 0.585 | 0.936 | 1.314 | 1.735 | 2.338 | 8.662 | 88.3 |
| Kafir (6) | 1.232 | 0.540 | 0.528 | 0.905 | 1.295 | 1.616 | 2.180 | 8.296 | 43.5 |
| Average | 1.228 | 0.522 | 0.551 | 0.918 | 1.266 | 1.695 | 2.130 | 8.310 | 66.5 |
| Daily average | 0.614 | 0.261 | 0.138 | 0.115 | 0.127 | 0.130 | 0.069 | —— | —— |

*Experiment (471) started March 3, 1924, 700 grams of soil+14 grams of organic material+210 cc water (slightly over one-half saturated). Values corrected for 800 grams of soil and 16 grams of organic material.

These data are almost a duplicate of those presented in Table 3 if the first two days of the former are omitted. The very rapid evolution of $CO_2$ evident during the first two days from the "A" residues is absent to a large extent from the "B" materials. This would indicate, as previously suggested, that much of the soluble compounds had either undergone decomposition or had diffused into the soil prior to collection. However, there is still a somewhat more marked formation of $CO_2$ from the kafir residue during the first few days after which

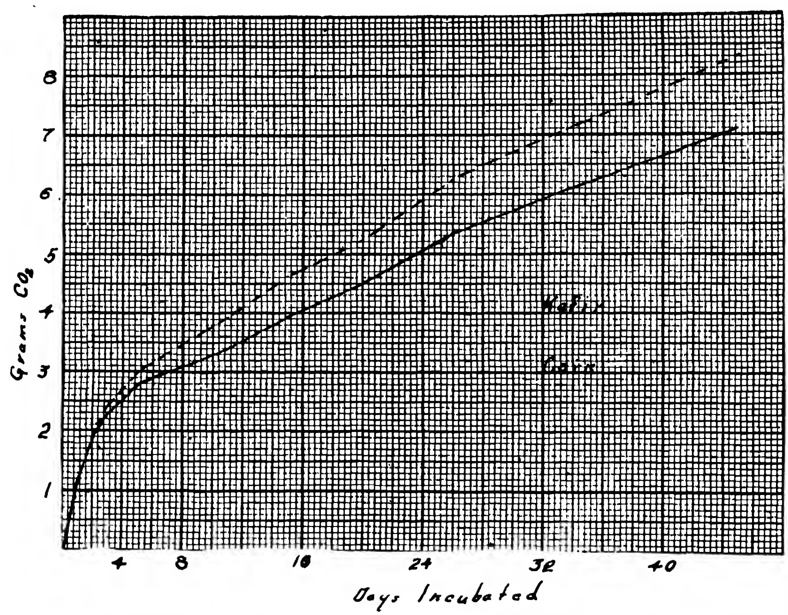


FIG. 2.—Evolution of $CO_2$ from corn (———) and kafir (-----) residues "A". From data in Table 3.

curves plotted for $CO_2$ evolved are, within the limits of error, exactly parallel throughout the entire 70 days that the experiment was continued.

### CORN AND KAFIR ROOTS "C"

These materials, it will be remembered, were composed entirely of roots which had undergone no decomposition. Data secured experimentally with these materials are presented in Tables 5 to 8, inclusive, and are shown graphically in Figs. 4 to 7, inclusive.

The data in Tables 5, 6, and 7, as reflected in Figs. 4, 5, and 6, are quite uniform in showing a very rapid evolution of $CO_2$ during the first few days with a tendency after the first four days for the curves to flatten out as in previous experiments. None of these experiments,

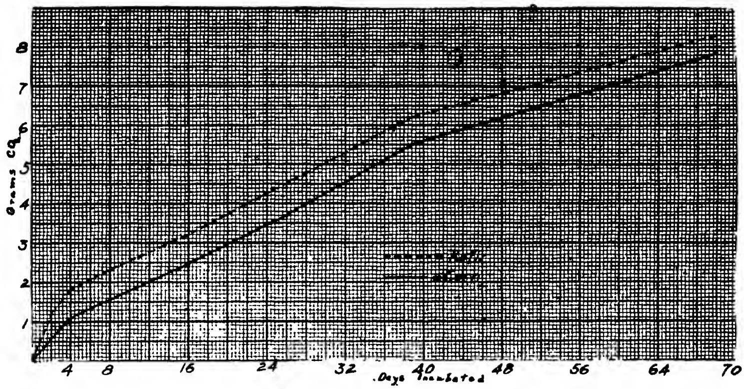

FIG. 3.—Evolution of $CO_2$ from corn and kafir residues "B". From data in Table 4.

TABLE 5.—*Decomposition of corn and kafir roots "C" in soil A.*

| Treatment and cylinder No. | Grams of $CO_2$ evolved from 800 grams of soil + 16 grams of roots* | | | |
|---|---|---|---|---|
| | June 25 2 days | June 27 2 days | June 30 3 days | Total 7 days |
| Corn (1) | 1.270 | 0.968 | 1.166 | 3.404 |
| Corn (3) | 1.518 | 1.144 | 1.144 | 3.806 |
| Corn (5) | 1.507 | 1.094 | 1.089 | 3.690 |
| Average | 1.432 | 1.069 | 1.133 | 3.633 |
| Daily average | 0.716 | 0.535 | 0.378 | —— |
| Kafir (2) | 1.919 | 1.188 | 1.100 | 4.207 |
| Kafir (4) | 1.920 | 1.353 | 1.204 | 4.477 |
| Kafir (6) | 1.969 | 1.325 | 1.111 | 4.405 |
| Average | 1.936 | 1.289 | 1.138 | 4.363 |
| Daily average | 0.968 | 0.645 | 0.379 | —— |

*Experiment (478) started June 23, 1924. 800 grams of soil + 16 grams of organic material + 240 cc water (slightly over one-half saturated).

TABLE 6.—*Decomposition of corn and kafir roots "C" in soil B.*

| Treatment and cylinder No. | Grams of $CO_2$ evolved from 800 grams of soil + 16 grams of organic material* | | | | | | |
|---|---|---|---|---|---|---|---|
| | Aug. 23 1 day | Aug. 24 1 day | Aug. 25 1 day | Aug. 26 1 day | Aug. 27 1 day | Aug. 29 2 days | Total 7 days |
| Corn (1) | 0.852 | 0.693 | 0.902 | 0.759 | 0.594 | 0.688 | 4.488 |
| Corn (3) | 0.880 | 0.456 | 0.853 | 0.555 | 0.523 | 0.649 | 3.916 |
| Corn (5) | 0.864 | 0.616 | 0.896 | 0.946 | 0.660 | 0.594 | 4.576 |
| Average | 0.865 | 0.588 | 0.884 | 0.753 | 0.592 | 0.644 | 4.327 |
| Daily average | 0.865 | 0.588 | 0.884 | 0.753 | 0.592 | 0.322 | —— |
| Kafir (2) | 1.716 | 0.786 | 1.073 | 0.764 | 0.707 | 0.754 | 5.800 |
| Kafir (4) | 1.705 | 0.946 | 1.292 | 0.836 | 0.633 | 0.792 | 6.204 |
| Average | 1.710 | 0.866 | 1.183 | 0.800 | 0.670 | 0.773 | 6.002 |
| Daily average | 1.710 | 0.866 | 1.183 | 0.800 | 0.670 | 0.387 | 6.002 |

*Experiment started August 22, 1926.

TABLE 7.—*Decomposition of corn and kafir roots "C" in soil B.*

| Treatment and cylinder No. | Grams of $CO_2$ evolved from 800 grams of soil+16 grams of organic material* | | | | | |
|---|---|---|---|---|---|---|
| | Aug. 7 1 day | Aug. 8 1 day | Aug. 9 1 day | Aug. 11 2 days | Aug. 14 3 days | Total 8 days |
| Corn (1)......... | 0.919 | 1.205 | 0.940 | 1.182 | 1.303 | 5.549 |
| Corn (3)......... | 0.979 | 1.182 | 0.847 | 1.095 | 1.029 | 5.132 |
| Corn (5)......... | 0.957 | 1.078 | 0.869 | 1.089 | 0.963 | 4.956 |
| Average.......... | 0.952 | 1.155 | 0.885 | 1.122 | 1.098 | 5.212 |
| Daily average..... | 0.952 | 1.155 | 0.885 | 0.561 | 0.366 | —— |
| Kafir (2)......... | 1.683 | 1.468 | 1.100 | 1.084 | 1.193 | 6.528 |
| Kafir (4)......... | 1.551 | 1.441 | 1.386 | 1.364 | 1.089 | 6.831 |
| Kafir (6)......... | 1.650 | 1.491 | 1.424 | 1.324 | 1.155 | 7.044 |
| Average.......... | 1.628 | 1.467 | 1.303 | 1.257 | 1.146 | 6.801 |
| Daily average..... | 1.628 | 1.467 | 1.303 | 0.629 | 0.382 | —— |

*Experiment (479) started Aug. 6, 1924, 800 grams of soil B+16 grams of organic material+240 cc water (slightly over one-half saturated).

however, were continued for more than eight days. These experiments also show a somewhat more marked evolution of $CO_2$ from the soil treated with kafir roots than from those cylinders treated with corn roots.

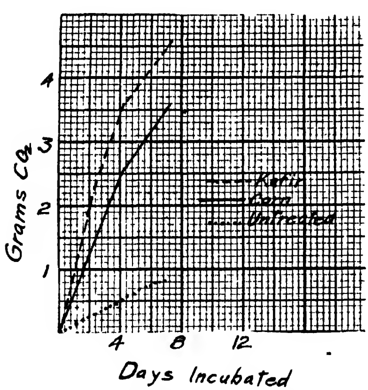


FIG. 4.—Evolution of $CO_2$ from corn and kafir residues "C". From data in Table 5.

The data presented in Table 9, however, when plotted, give practically a straight line from the beginning with no appreciable difference between the $CO_2$ evolved from the two treatments. Since this is the only instance in which the data when plotted assumes a straight line, it possibly should be regarded as abnormal, though showing that conditions may arise in which such a type of decomposition may be expected.

From the data submitted in the preceding tables, one would be led to believe that there probably exists a slight qualitative or quantitative difference in the composition of corn and kafir roots and stubble which makes it possible for the latter to undergo a slightly more rapid biological decomposition when placed under suitable conditions, such differences in the rates of decomposition apparently being confined largely to the early stages in the decomposition.

### INFLUENCE OF CORN AND KAFIR RESIDUES UPON ACCUMULATION OF NITRATE NITROGEN IN SOIL

Considerable significance has been attached to the possible harmful influence that sorghum residues may have upon the nitrate nitrogen content of a soil and a consequent indirect effect upon the succeeding crop. The writer (4) again calls attention to a clear cut distinction that should be made between "nitrification" and "nitrate accumulation." Many writers continue to refer to the action of any substance that prevents the accumulation of nitrate nitrogen as being harmful to nitrification. If, as is intimated by Breazeale (1), there is set free a toxic compound or compounds in the decomposition of kafir residues, such a substance might act directly upon the nitrifying organisms, stopping their activity and thereby preventing nitrification or the formation of nitrate nitrogen from other forms. On the other hand, if the effect of the kafir residue is to stimulate microbial activity in general, as suggested by Conrad (2), or more specifically as intimated by Wilson and Wilson (6), the resulting increase in

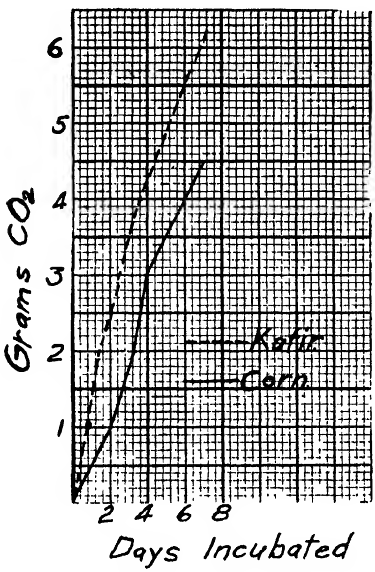


FIG. 5.—Evolution of $CO_2$ from corn and kafir residues "C". From data in Table 6.

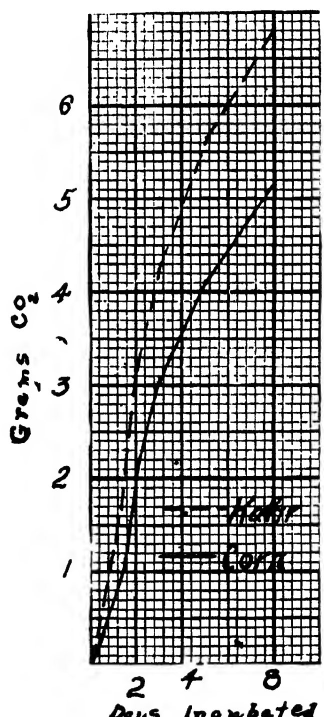


FIG. 6.—Evolution of $CO_2$ from corn and kafir residues "C". From data in Table 7.

TABLE 8.—*Decomposition of corn and kafir roots "C" in soil B.*

| Treatment and cylinder No. | Grams of $CO_2$ evolved from 800 grams of soil+16 gram of corn and kafir roots "C"* | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Apr. 26 1 day | Apr. 28 2 days | Apr. 30 2 days | May 2 2 days | May 5 3 days | May 8 3 days | May 12 4 days | May 18 6 days | May 25 7 days | Total 30 days |
| Corn (2) | 0.187 | 0.440 | 0.594 | 0.539 | 0.671 | 0.506 | 0.792 | 1.232 | 1.518 | 6.479 |
| Corn (4) | 0.198 | 0.352 | 0.598 | 0.495 | 0.649 | 0.506 | 0.715 | 1.078 | 1.408 | 5.999 |
| Corn (6) | 0.165 | 0.402 | 0.638 | 0.462 | 0.671 | 0.517 | 0.737 | 1.155 | 1.606 | 6.353 |
| Average | 0.183 | 0.398 | 0.610 | 0.499 | 0.664 | 0.510 | 0.748 | 1.155 | 1.511 | 6.278 |
| Daily average | 0.183 | 0.199 | 0.305 | 0.250 | 0.221 | 0.170 | 0.187 | 0.192 | 0.216 | —— |
| Kafir (3) | 0.198 | 0.572 | 0.523 | 0.473 | 0.627 | 0.451 | 0.726 | 1.100 | 1.474 | 6.144 |
| Kafir (5) | 0.170 | 0.528 | 0.385 | 0.418 | 0.594 | 0.451 | 0.759 | 1.386 | 1.562 | 6.253 |
| Average | 0.184 | 0.550 | 0 454 | 0.446 | 0.611 | 0.451 | 0.742 | 1.243 | 1.518 | 6.199 |
| Daily average | 0.184 | 0.275 | 0.227 | 0.223 | 0.204 | 0.150 | 0.185 | 0.207 | 0.217 | —— |

*Experiment (500) started April 25, 1928, 800 grams of soil B+16 grams of organic material "C"+208 cc water (one-half saturated)

nitrate nitrogen consumption by these organisms might easily exceed its formation resulting in a decrease or deficiency, yet the activity of the nitrifying organisms might in no way be interfered with. The net results in both instances would be the same, namely, a decrease in the nitrate nitrogen content of the soil, yet the processes by which this deficiency resulted are fundamentally different.

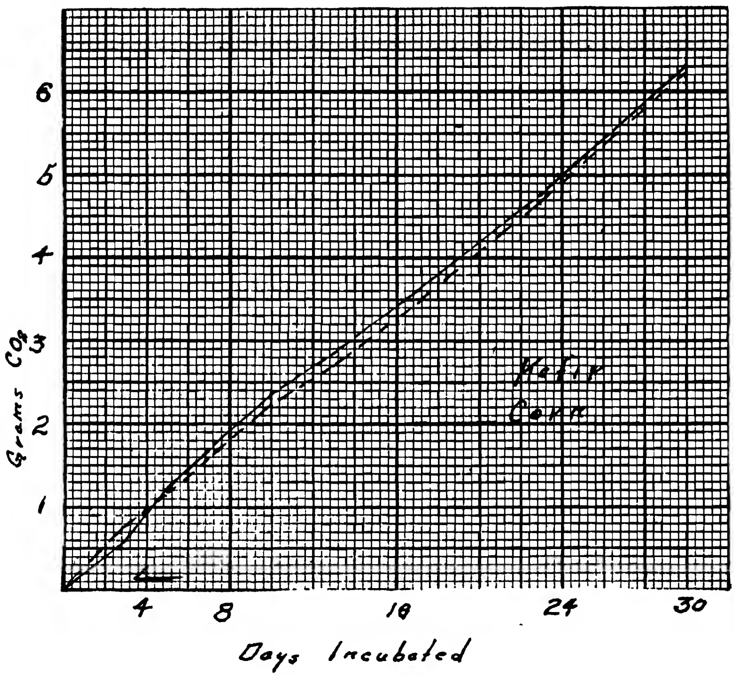


FIG. 7.—Evolution of $CO_2$ from corn (——) and kafir (-----) residues "C". From data in Table 8.

To gain information as to the relative effect of the two crop residues being studied upon the nitrate nitrogen content of the soil, quantitative $NO_3$ determinations were made on the soil from a number of the experiments already recorded. However, the conditions existing in a cylinder of soil through which a current of air is being continuously drawn may not be very satisfactory for nitrate nitrogen accumulation. Probably partially as a result of these conditions and partly because of the presence of the organic materials added, nitrate nitrogen was found in measurable quantities in only one instance, namely, the experiment reported in Table 4. A glance at the last column of this table will show that as an average the $NO_3$ content of the kafir-treated soil was approximately three times that of the

soil to which the corn residue was added when the experiment was discontinued. The $CO_2$ data in this particular experiment, however, indicate that probably much of the easily decomposable material had disappeared from the stubble before it was collected.

In order to study the influence of the three batches of material upon nitrate nitrogen accumulation under comparable conditions, the experiments reported in Tables 9 and 10 were carried out. In these experiments 100 grams of soil plus the desired quantity of organic material and sufficient water to bring the moisture content to two-thirds saturation was placed in wide-mouthed 500-cc bottles stoppered with cotton and incubated at room temperature, conditions known to be highly favorable to nitrate nitrogen formation. The experiments recorded in Tables 9 and 10 were identical except that in the latter 60 mgms of nitrogen as $(NH_4)_2SO_4$ were added to each sample in order that there might be no deficiency in nitrogen for the nitrifying organisms. Incubation was for 63 days and $NO_3$ determinations were made upon the entire sample by the phenol-disulfonic acid method.

The data in Table 9 are quite conclusive in showing the detrimental effect of carbonaceous materials upon the accumulation of nitrate nitrogen. Also, as the quantities of organic matter added increased, the detrimental effect became more marked. As was probably to be expected from the $CO_2$ studies, the fresh roots showed the most marked retarding effect followed by the residues collected immediately after harvest. In other words, the detrimental effect upon nitrate nitrogen accumulation was more or less proportional to the rate of $CO_2$ evolved during the early periods of incubation. All these results were probably to be expected. The interesting fact in connection with the present investigation, though, is that in only one of the nine comparisons did the kafir residue exert a more harmful effect upon the accumulation of nitrate nitrogen than did the corn residue. In this respect the results are possibly contrary to what might be expected, nevertheless they are qualitatively identical with those reported by Wilson and Wilson for comparable incubation periods.

The results recorded in Table 10 indicate that where such excessive quantities of crop residues as 2% are added to a soil, the subsequent influence upon the nitrate nitrogen content may not be perceptible after a few weeks, provided the quantity of available nitrogen is high. Only in those instances where 1 and 2% of corn roots and 2% of kafir roots were added is there any indication of a depressing effect and it is possible that the lower quantities recorded for these samples are within the experimental error which for the six checks is $\pm 72$ p.p.m. Again the kafir is, if anything, less harmful than the corn.

TABLE 9.—*Effect of corn and kafir crop residues upon the accumulation of nitrate nitrogen in soil after incubation for 63 days.*

| Sample No. | Organic material per 100 grams soil | $NO_3$ in p.p m. | Average $NO_3$ in p.p.m. | Organic material per 100 grams soil | $NO_3$ in p.p.m. | Average $NO_3$ in p.p.m. | Organic material per 100 grams soil | $NO_3$ in p.p.m. | Average $NO_3$ in p.p.m. |
|---|---|---|---|---|---|---|---|---|---|
| 1 | none | 160 | 166 | none | 150 | 155 | none | 137 | 149 |
| 2 | none | 172 | — | none | 160 | — | none | 160 | — |
| 3 | 0.5 gram corn "A" | lost | 20 | 0.5 gram corn "B" | 84 | 75 | 0.5 gram corn "C" | trace | race |
| 4 | 0.5 gram corn "A" | 20 | — | 0.5 gram corn "B" | 66 | — | 0.5 gram corn "C" | none | — |
| 5 | 1.0 gram corn "A" | trace | 13 | 1.0 gram corn "B" | 42 | 28 | 1.0 gram corn "C" | none | none |
| 6 | 1.0 gram corn "A" | 25 | — | 1.0 gram corn "B" | 15 | — | 1.0 gram corn "C' | none | — |
| 7 | 2.0 grams corn "A" | trace | trace | 2.0 grams corn "B" | trace | trace | 2.0 grams corn "C" | none | none |
| 8 | 2.0 grams corn "A" | trace | — | 2.0 grams corn "B" | trace | — | 2.0 grams corn "C" | none | — |
| 9 | 0.5 gram kafir "A" | 52 | 49 | 0.5 gram kafir "B" | lost | 80 | 0.5 gram kafir "C" | 15 | 8 |
| 10 | 0.5 gram kafir "A" | 45 | — | 0.5 gram kafir "B" | 80 | — | 0.5 gram kafir "C" | trace | — |
| 11 | 1.0 gram kafir "A" | 16 | 18 | 1.0 gram kafir "B" | 50 | 25 | 1.0 gram kafir "C" | none | none |
| 12 | 1.0 gram kafir 'A" | 20 | — | 1.0 gram kafir "B" | none | — | 1.0 gram kafir "C" | none | — |
| 13 | 2 0 grams kafi: "A" | trace | trace | 2.0 grams kafir "B" | 48 | 32 | 2.0 grams kafir "C" | none | none |
| 14 | 2.0 grams kafir "A" | trace | — | 2.0 grams kafir "B" | 17 | — | 2.0 grams kafir "C" | none | — |

"A" = Stubble and roots collected immediately after harvest.
"B" = Stubble and roots collected in early spring.
"C" = Roots from plants grown in cylinders.

TABLE 10.—*Effect of corn and kafir crop residues upon the accumulation of nitrate nitrogen in soil to which ammonium sulfate was added after incubation for 63 days.*

| Sample No. | Organic material per 100 grams soil | $NO_3$ in p.p.m. | Average $NO_3$ in p.p.m. | Organic material per 100 grams soil | $NO_3$ in p.p.m. | Average $NO_3$ in p.p.m. | Organic material per 100 grams soil | $NO_3$ in p.p.m. | Average $NO_3$ in p.p.m. | General average |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | none | 1,200 | 1,305 | none | 1,476 | 1,500 | none | 1,410 | 1,455 | 1,420 |
| 2 | none | 1,410 | —— | none | 1,524 | —— | none | 1,500 | —— | —— |
| 3 | 0.5 gram corn "A" | 1,500 | 1,500 | 0.5 gram corn "B" | 1,500 | 1,500 | 0.5 gram corn "C" | 1,500 | 1,500 | 1,500 |
| 4 | 0.5 gram corn "A" | 1,500 | —— | 0.5 gram corn "B" | 1,500 | —— | 0.5 gram corn "C" | lost | —— | —— |
| 5 | 1.0 gram corn "A" | 1,500 | 1,578 | 1.0 gram corn "B" | 1,410 | 1,433 | 1.0 gram corn "C" | 1,332 | 1,266 | 1,426 |
| 6 | 1.0 gram corn "A" | 1,656 | —— | 1.0 gram corn "B" | 1,455 | —— | 1.0 gram corn "C" | 1,200 | —— | —— |
| 7 | 2.0 grams corn "A" | 1,600 | 1,628 | 2.0 grams corn "B" | 1,500 | 1,478 | 2.0 grams corn "C" | 1,230 | 1,230 | 1,445 |
| 8 | 2.0 grams corn "A" | 1,656 | —— | 2.0 grams corn "B" | 1,455 | —— | 2.0 grams corn "C" | 1,230 | —— | —— |
| 9 | 0.5 gram kafir "A" | 1,500 | 1,478 | 0.5 gram kafir "B" | 1,410 | 1,433 | 0.5 gram kafir "C" | 1,460 | 1,435 | 1,449 |
| 10 | 0.5 gram kafir "A" | 1,455 | —— | 0.5 gram kafir "B" | 1,455 | —— | 0.5 gram kafir "C" | 1,410 | —— | —— |
| 11 | 1.0 gram kafir "A" | 1,500 | 1,524 | 1.0 gram kafir "B' | 1,548 | 1,524 | 1.0 gram kafir "C" | 1,392 | 1,416 | 1,489 |
| 12 | 1.0 gram kafir "A" | 1,548 | —— | 1.0 gram kafir "B" | 1,500 | —— | 1.0 gram kafir "C" | 1,440 | —— | —— |
| 13 | 2.0 grams kafir "A" | 1,455 | 1,433 | 2.0 grams kafir "B" | 1,476 | 1,434 | 2.0 grams kafir "C" | 1,332 | 1,332 | 1,400 |
| 14 | 2.0 grams kafir "A" | 1,410 | —— | 2.0 grams kafir "B" | 1,392 | —— | 2.0 grams kafir "C" | 1,332 | —— | —— |

## DISCUSSION

It should be kept clearly in mind that the results here reported were secured in the laboratory under conditions little resembling those existing in the field and to this extent they are limited in their application. However, upon purely theoretical considerations, the writer can see no reason why qualitatively similar results should not be secured under field conditions.

In the first place, there is nothing unusual or perhaps unexpected in any of the $CO_2$ data presented. It is a well-established fact that different organic compounds undergo decomposition at different rates when added to the soil. Among the most easily decomposable compounds are the soluble carbohydrates—the sugars. Conrad has shown that the sorghum roots as a class contain a much higher percentage of sugars than do corn roots. Likewise, Wilson and Wilson have reported a much higher percentage of soluble material present in sorghum roots. It would be expected, therefore, that when such materials are added to a soil, a more rapid decomposition, at least of the sugars present, would take place. The data submitted in the present paper tend to substantiate those of Wilson and Wilson in showing, as a rule, a more rapid evolution of $CO_2$ from soil treated with kafir residues than from a similar corn-residue treated soil during the first few days after treatment. The differences in favor of kafir would depend, of course, upon the excess quantities of easily decomposable materials present compared with corn. Conrad's data show a wide variation in the percentage of sugars present in different varieties of sorghums. In one and the same variety variations might be expected depending upon the conditions as to age, subsequent treatment, etc., attending the collection of the material. Just as soon as the plant cells die there would be a rapid diffusion of soluble compounds, including sugars, into the soil, provided sufficient moisture were present.

The differences in $CO_2$ evolved in favor of sorghum reported by Wilson and Wilson are greater than in the present data, probably due to some of the factors discussed in the preceding paragraph. However, such differences had practically disappeared in their data within a week, while they persisted longer in our experiments.

There is nothing in the data her submitted that would lend support to the theory advanced by Breazeale, i.e., a decreased $CO_2$ formation, to account for the deflocculating effect of sorghums. In fact, quite the reverse is true, since in no instance has there been less $CO_2$ evolved from kafir residues than from corn, yet no one has accussed corn of

deflocculating the soil. Incidentally, the writer has noted evidence of a deflocculating effect of dry kafir stubble when mixed in soil in certain experiments.

Another well-established fact in soil biology is that the addition of available carbonaceous materials to a soil stimulates the development of soil micro-organisms, particularly bacteria and fungi. The more readily available the material, other things being favorable, the greater the stimulating effect. This increased growth, frequently visible to the unaided eye if fungi, necessarily increases the demands upon the soil for available nitrogen. Nitrate nitrogen is among the most readily available forms for many organisms. Hence, there will almost invariably result a decrease in soluble nitrogen, especially nitrate nitrogen, following the addition of organic materials available as microbial food, provided such material is low in nitrogen. Quantitatively this decrease in soluble nitrogen will depend upon the extent of such growth which in turn is dependent upon the supply of available food added. As to whether it is quantitatively significant will also depend upon the total quantity of soluble nitrogen in the soil. If the latter is high and the quantity of organic material added small, the decrease in soluble nitrogen may not even be perceptible. On the other hand, if the reverse conditions obtain, such forms of nitrogen as nitrate may completely disappear and remain quantitatively absent for a long or short period of time, depending upon the demands for nitrogen created by continued active growth of the soil micro-organisms.

As to whether corn and kafir stubble will cause a perceptible prolonged decrease in the nitrate content of a soil will depend upon the equilibrium existing in any given soil between the factors discussed in the preceding paragraph. Evidently the addition of such quantities as were used in the experiments reported here, as well as those reported by Wilson and Wilson, will, under the condition obtaining, cause a temporary disappearance of nitrate nitrogen where the quantity of soluble nitrogen was small, i.e., where no nitrogen or small quantities were added. On the other hand, the data contained in Table 10 show that the excessive quantity of 2% of either of these residues may not perceptibly influence the nitrate nitrogen content of a soil provided its nitrogen content is sufficiently high. Also, it is evident from these data that in the presence of quantities of these two crop residues far in excess of any condition ever encountered normally, and where the residues are rendered more available than would obtain under field conditions by thoroughly disintegrating and mixing uniformly in the soil, nitrate nitrogen

will begin to reappear in large quantities within a few days to a few weeks time, even though no additional nitrogen is supplied.

The particular phase of the problem of most interest from the present point of view is not the absolute but rather the relative effect upon nitrate accumulation of the two crop residues being studied. Since there are reasons to believe that the available microbial food content of sorghum residues is higher than for corn, then it would be reasonable to expect that the former would cause a more rapid disappearance of nitrate nitrogen than the latter. Wilson and Wilson found such to be the case. However, in every comparison reported by these investigators the nitrate content of the sorghum residue treated soil was equal to or exceeded the corn residue treated soil within a few weeks time. The same is true in the comparisons recorded in Table 9. Where the larger quantities, 2% and 4%, of sorghum roots were added, Conrad also recorded a marked increase in nitrate nitrogen content within a few days. The quantity of $NO_3$ recorded after six weeks' incubation was three times as great where 4% sorghum roots was added as in the check which received no organic material.

Sewell's data, collected over a period of seven years, relative to the comparative effect of corn and kafir upon the quantities of nitrates in field soils at wheat seeding time, show an average difference of only 2.6 p.p.m. of $NO_3$ in favor of corn, the nitrate content of the kafir soil exceeding that of the corn soil two out of seven years. If there is any time of the season when the kafir stubble should exert a detrimental effect upon the nitrate content of the soil, it would seem to be soon after harvest or near the seeding time for winter wheat. Hence the laboratory data presented in this paper are in substantial agreement with the findings under field conditions at this station.

To what extent the data presented in this paper can be used to support or refute the various theories advanced to account for the deleterious effect of sorghum upon the succeeding crop is questionable. Only two or three suggestions will be offered.

There is little in support of Breazeale's toxic theory. Certainly no substance very toxic to the micro-organic population of the soil as a whole is set free. The evolution of $CO_2$ is perhaps the best criterion of microbial activity and in the data here reported it was always equal or greater from kafir residue than from corn. Also, in the presence of available ammonia no harmful effect upon the nitrifying organisms, a supposedly responsive group, is evident.

In this connection it might be suggested that the conditions under which Breazeale secured his toxic product are open to serious criticism from a microbiological point of view.

It is a well-established fact that anaerobic bacteria will thrive in a comparatively shallow culture solution if mixed with aerobic organisms, or even in pure cultures if large quantities of finely divided solid substances are present. With the abundant sources of available energy in the form of soluble carbohydrates—a condition essential for anaerobic growth—present in sorghum roots, but practically absent from the corn residues, the conditions in Breazeale's sorghum cultures would be almost ideal for anaerobic fermentation. Furthermore, Breazeale intimates that offensive odors, an almost sure indication of anaerobic activity, were developed. If anaerobic conditions did obtain, numerous intermediate decomposition compounds toxic to higher plants might have temporarily accumulated. Upon diffusion to the surface, or if for any other reasons conditions became aerobic, such compounds would be rapidly oxidized by aerobic organisms to inoffensive end-products. Under natural well-areated soil conditions where normal decomposition is taking place, anaerobic conditions probably seldom obtain. The really surprising fact in connection with Breazeale's experiments is that plants grew in any of his cultures during early stages of decomposition.

That the harmful effect of the sorghums is due largely to their sugar content, according to Conrad's theory, is also questionable. Breazeale states that the harmful effect "is characteristic of both saccharine and non-saccharine varieties" of sorghum. Sugars undoubtedly stimulate a rapid disappearance of nitrates. The rapidity with which they are utilized by such large numbers of soil microorganisms, together with the rapid rate at which they would diffuse from dead roots and stubble into the surrounding soil, would assure the almost immediate and complete disappearance of any quantities that have been observed in forage or grain sorghums. In fact, Conrad states that no sugar could be recovered three days after large quantities of sorghum roots containing 14.6% sugar were added to a soil.

The writer has been unable to detect sugar qualitatively 24 to 72 hours after adding to a soil many times the amounts that would ever be encountered under field conditions following the growth of a sorghum.

As to the influence of sorghum residues upon the nitrate content of the soil and in turn growth of plants therein, it would appear that any detrimental effect would have to be exerted within a few days or at most a few weeks after the residues were plowed under. After a very brief period corn residues certainly depress nitrate accumulation to as marked an extent as do sorghum. Under Kansas condi-

tions, where the average residue is estimated to be only approximately 1,250 pounds per acre,[4] or 0.05% instead of 0.5%, the smallest quantities tested experimentally by Wilson and Wilson or in the present investigation, the resulting delay in nitrate accumulation would undoubtedly not be nearly as long as those recorded. Any harmful influence upon a crop, such as wheat planted immediately following a sorghum, resulting from a deficiency in available nitrogen would apparently have to be exerted during the first few days of growth.

## SUMMARY

Available evidence concerning the relative rates of decomposition of corn and kafir residues would indicate that there is present in kafir limited quantities of carbonaceous material somewhat more easily oxidizable by micro-organisms than exist in corn. Such material being readily available as carbonaceous food tends to stimulate temporarily a more rapid development of micro-organisms, probably resulting in a somewhat more rapid assimilation of soluble nitrogen. Such material is probably soon exhausted. Thereafter decomposition of the two materials run practically parallel and if any further influence is exerted upon the nitrate content of the soil it is a stimulation, rather than a retardation, in nitrate accumulation by the kafir as compared to corn residues.

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[4]This value is based upon the average yield of grain and forage reported by Sewell (Table 1). Dr. E. C. Miller has estimated the root and stubble of the corn plant to equal 12% of the grain and forage and in the case of kafir to equal only 9%.

# THE CONTRAST IN RESPONSE OF KAFIR AND MILO TO VARIATIONS IN SPACING[1]

R. E. KARPER[2]

The grain sorghum crop in the United States is becoming of such magnitude and importance that investigators working with the crop are eagerly seeking means and methods of increasing yields. The objects of the investigations reported here were to determine, first, the optimum distance between plants in the row for kafir and milo, and second, to discover the nature of the relationship existing between various degrees of spacing and grain yields in these two most widely grown varieties of grain sorghum. The contrasting response of these two grain sorghums to different spacings in the row, as affecting yields and tillering, are also pointed out, and the effect that such widely different varietal reactions can have on the accuracy of other investigational work involving different varieties is indicated.

Agronomists working with other crops have determined fairly well the best varieties, rates of seeding, dates of seeding, and the best cultural practices for various regions and have made possible increases in the general yield levels. The underlying and fundamental reason why some varieties, methods, or practices are superior in some of the older crops has been determined. In the case of the grain sorghums, much more intensive and well-planned work must be done on rather simple agronomic problems before adequate data are available as a basis for sound recommendations. Field experiments, for example, to determine the response of different varieties to various rates and dates of planting are almost necessary before adequate interpretations can be made of plat work already done in variety testing, rate of planting, and date of planting and before such interpretations can have a general application. A plan of field experiments inclusive of the many varieties, the necessary range of rates of planting or row space, and of dates of planting, together with sufficient replication of the plats, involves a large amount of land and a great deal of labor, both of which are not always available. Sorghum varieties have been developed to cover a wide range of uses and conditions. Their chief use and adaptability may be strictly grain production, dual grain and forage, strictly forage, or they may be grown for other purposes, such as the brush in broom corn. Varieties within a single group, such as

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the grain sorghums, may be very early or very late and rank in their growing habits. Some sucker freely and others not at all. Their reaction, therefore, to varying space in the row, or dates of planting, may show a considerable variation.

Sieglinger (4)[3] has pointed out that grain sorghum varieties may be roughly grouped into two classes, namely, the freely suckering types, such as milo and feterita, and those producing few suckers, such as kafirs and kaoliangs. This, of course, is a broad grouping as there is a wide range in the variation of different strains and varieties. He states that varieties which sucker freely produced the best yields when space between plants in the row was increased, and the sparsely suckering sorts gave better yields as the space was decreased. His statements, in general, are in agreement with the data reported here. Hastings (2), working with milo at San Antonio, Texas, shows that when the seed was planted thick, or plants spaced close in the row, higher yields of grain resulted. These results, however, can be wholly accounted for by the fact that the work was done in an area where the sorghum midge is prevalent. Thick seeding of milo suppresses the development of suckers and side branches and forces uniform and early maturity of the main heads, thus enabling them to escape midge injury and thereby increase the yield, even though additional potential yielding power is sacrificed through close spacing.

## EXPERIMENTAL CONDITIONS AND METHODS

Spacing work reported herein extends over a 10-year period at the Texas Substation at Lubbock and includes the two most important varieties of grain sorghums. The experiment was planned to include, by 3-inch intervals, each variation lying between a minimum of 3 inches and a maximum of 36 inches in the row. Data on the average yield of Dwarf Yellow milo and Dwarf Blackhul kafir for each of the 12 rates of planting involved are shown for the 10-year period, 1916–25. During this time the records were continuous and unbroken, except for three seasons in milo and one in kafir when a poor stand was obtained on the plats having a 3-inch spacing between plants.

Plats were one twenty-second acre, net, in size, and consisted of seven rows 8 rods long, the two outside rows serving as guard rows and the five inside rows being harvested for yield. The distance between rows was 3 feet. A lister planter was used and planting was done between May 1 and 15, usually around May 5, which is fairly early for this latitude.

[3]Reference by number is to "Literature Cited," p. 354.

The seeding rate was heavy so as to secure an ample stand and a uniform distribution of plants. When the seedlings were 2 to 4 inches high, plats were thinned by hand to the desired distance between plants and the stands counted and recorded. While it is not thought necessary to present complete data here on the actual stand and percentage stand obtained in each case, it should be stated that the plats were discarded when more than a slight variation from perfect stands prevailed. As would be expected, deficiencies in stands were more frequently encountered in the closely spaced plats and for this reason it was necessary to discard results from the 3-inch spacing in several of the years. On the whole, slightly better stands were obtained on the thicker rates with kafir than with milo; and when all plats are considered over the 10 years covered by these experiments, the stands, when calculated on a percentage basis, have averaged 98% perfect for milo and 99% for kafir. Average percentage stands for each of the 12 spacings involved appear in Table 1.

TABLE 1.—*Relation of row space per plant to yield of kafir and milo, average percentage stand, and grain yield, 1916–25.*

| Distance between plants, inches | Kafir Stand % | Kafir Bushels per acre | Milo Stand % | Milo Bushels per acre |
|---|---|---|---|---|
| 3 | 96.7 | 24.86* | 88.6 | 22.17† |
| 6 | 98.8 | 25.51 | 93.0 | 20.90 |
| 9 | 100.0 | 24.12 | 96.5 | 21.62 |
| 12 | 96.6 | 23.14 | 97.8 | 23.35 |
| 15 | 100.0 | 22.71 | 99.6 | 23.17 |
| 18 | 100.0 | 23.01 | 100.0 | 26.46 |
| 21 | 100.0 | 21.68 | 100.0 | 26.28 |
| 24 | 100.0 | 21.24 | 100.0 | 26.27 |
| 27 | 100.0 | 20.68 | 100.0 | 26.44 |
| 30 | 100.0 | 22.41 | 100.0 | 25.91 |
| 33 | 100.0 | 21.94 | 100.0 | 26.29 |
| 36 | 100.0 | 21.37 | 100.0 | 25.65 |
| Average | 99.3 | 22.72 | 97.7 | 24.54 |

*9 years. †7 years.

## EFFECTS OF SPACING UPON GRAIN YIELDS AND TILLERING

Table 1 shows the average yields of Dwarf Blackhul kafir and Dwarf Yellow milo for the years 1916–25 inclusive, during which time the plats were thinned to afford various row spaces per plant. The spacing treatments varied by 3-inch intervals, with close spacing of 3 inches between plants and a wide spacing of 36 inches as the two extremes. During most seasons these two limits were sufficiently

wide to include the optimum somewhere between the extremes. However, in very dry years, such as 1917 and 1924, the maximum yields were made by the plats having the widest spacing and perhaps higher yields would have followed still wider spacing. Poor stands in the plats with 3-inch spacings rendered the yields unreliable for kafir in 1917 and for milo in 1917, 1922, and 1925, so these yields are omitted. For the sake of brevity, only the average yields are tabulated in this paper, and since actual yields of both kafir and milo are plotted in the accompanying graphs for each of the respective years, it does not seem necessary to include also a tabulation of the annual yield data.

Kafir and milo have a directly opposite reaction to wide and narrow spacing of plants in the row, as may be seen by referring to Table 1 and the accompanying graphs. The yield of kafir decreases and that of milo increases as the space between plants increases. Lowest yields of kafir, on the average, occur around the 27-inch spacing. Above this point there are slight increases in yield, due to the influence of the two years, 1917 and 1924. These two years were extremely dry, the total annual rainfall in each being below 10 inches. The yields, therefore, were low, and as would be expected, increased directly as the distance between plants increased. Favorable moisture conditions in 1919 and 1925 enabled the extremely wide spacings to compensate their yields through tillering, which helps to accentuate the tendency for the widest spacings in kafir to advance slightly in yield. (See Fig. 1.)

Turning to milo, exactly the opposite effect of close and wide spacing upon yield will be noted. Yields decreased rapidly, on the average, when plants in the row were spaced closer than 18 inches. Above this point, however, there is little variation, indicating that milo is not so restricted in its optimum space requirements as kafir. Distances between 18 and 33 inches seem to be almost equally favorable and within this range the milo plant is able to make its own adjustments through tillering. Graphs in Fig. 2 indicate a rather consistent performance of milo from year to year, with the maximum yields grouped around the upper limits of spacing. This distribution of yields is generally true in all seasons except 1919 and 1925 when the distribution of rainfall was more nearly favorable to uniform development of the crop, whether spaced close or wide apart in the row.

The differences between kafir and milo in response to variations in spacing may be assigned largely to their inherently different stooling habit. The milo plant approaches a determinate habit of growth when moisture is not plentiful but stools freely when fertility and

moisture conditions are favorable, while kafir is indeterminate in its growth and normally not inclined to sucker freely. Milo, if planted thin enough, can, by tillering, thus adjust its own spacing distance

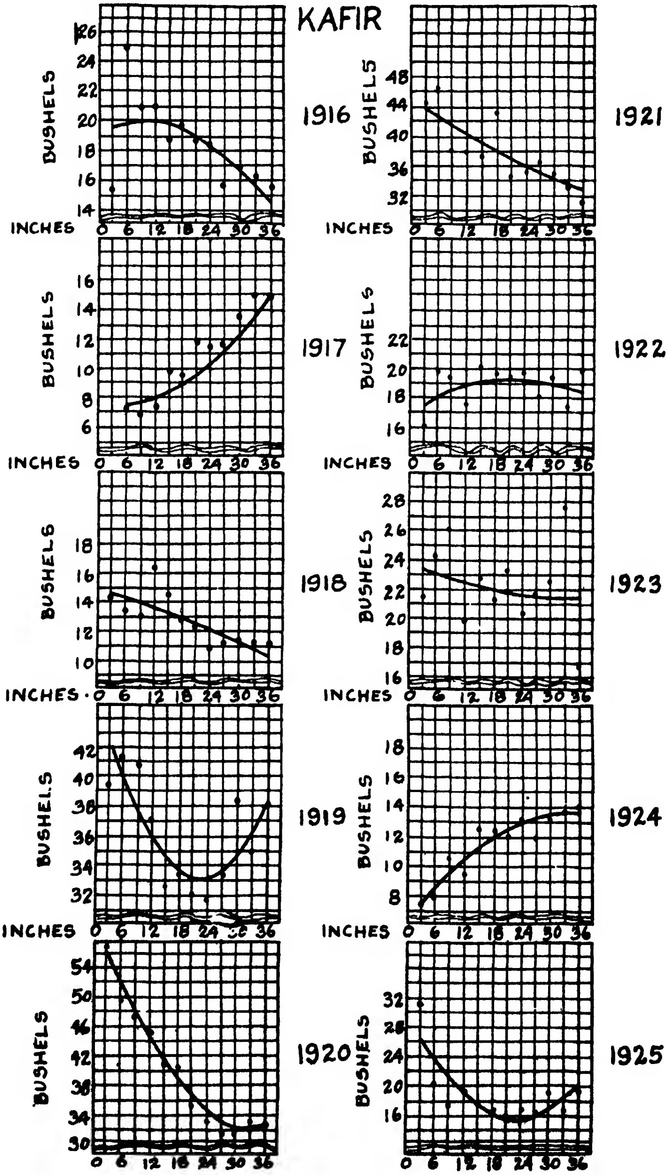


FIG. 1.—Second degree parabola fitted to show the relation of distance between plants in the row to yield of kafir, 1916–25.

to a degree of accuracy entirely beyond the capacity of the grower who is without definite knowledge of the amount of moisture that

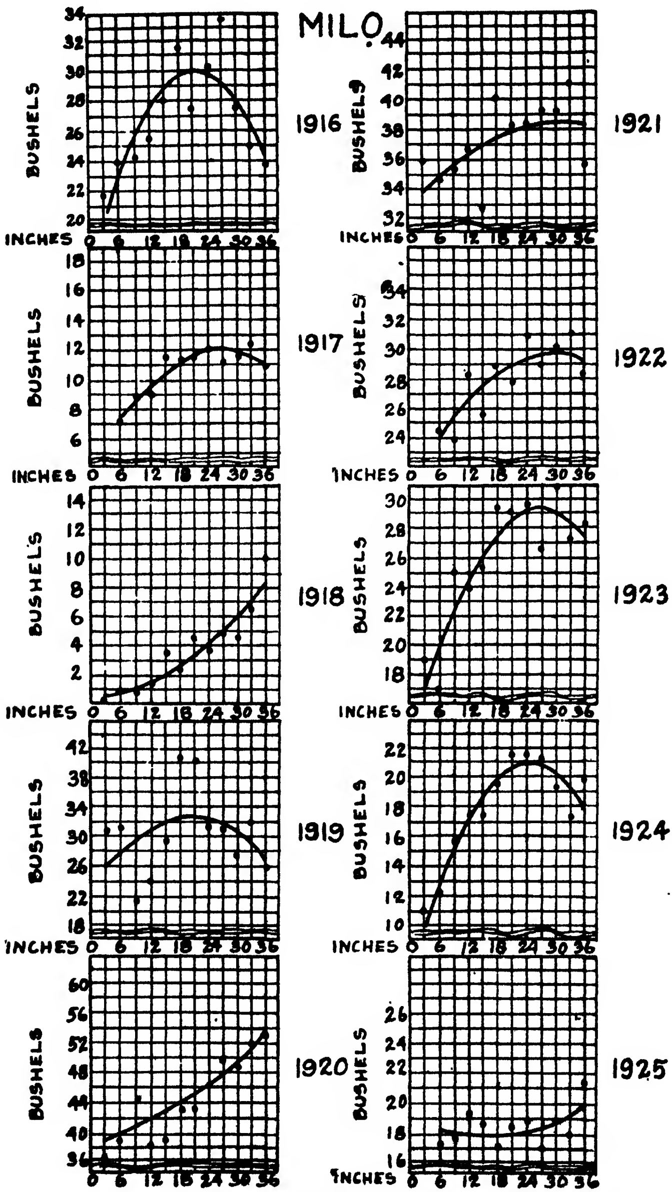


FIG. 2.—Second degree parabola fitted to show the relation of distance between plants in the row to yield of milo, 1916–25.

is going to be at the command of the crop. Apparently little advantage would be gained by striving for a definite spacing of 24 or 30 inches, for instance, but a loss in yield would follow spacing closer than 18 inches. Viewed from this angle, stooling is an asset to the milo plant. Its range of optimum row space, 18 to 30 inches, is twice as great as the optimum range, 3 to 9 inches, for kafir. Maximum yields of milo seem less dependent upon exactness in rate of seeding requirements than is the case with kafir and other sparsely tillering varieties which depend pretty largely upon a thick seeding rate for optimum yield.

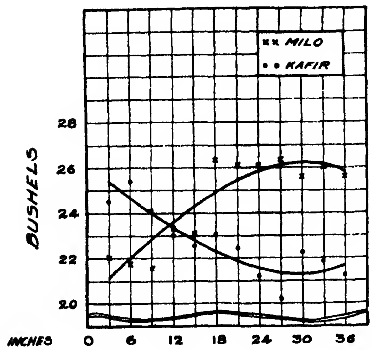


FIG. 3.—Curves showing 10-year average yields of kafir and milo in relation to distance between plants in the row.

## NATURE OF THE RELATIONSHIPS

A clearer picture of the trend and grouping of the yields over the range of spacing and for the various seasons included in this experiment is shown by the graphs in Figs. 1, 2, and 3. The curve used to describe the relationship of row space per plant to yield is a second degree parabola fitted by the method of least squares. The equation to this curve is $y=a+bx+cx^2$. Actual yields are also plotted on the graph. The non-linear regression between rate of seeding and yield in kafir and milo can more readily be shown by mathematically fitting this type of curve to the data. In choosing this type of curve arbitrarily and applying it to each year's data, it can not be expected of course, that a good fit will result in all cases, but on the whole it describes the relationship better than when a linear regression is assumed. Assuming that the optimum spacing for kafir and milo lies somewhere between the limits of spacing used here, the important consideration is to determine the point at which grain yield begins to fall off with increase or decrease of distance between plants.

It is seen in Fig. 3 that kafir and milo react in an exactly opposite manner under conditions of close and wide spacing of plants in the row. The yields of milo increase steadily as the space allotted increases, but when the distance between plants has reached 30 inches, a decrease in yield follows. Yields of kafir decrease as the space

TABLE 2.—*Comparison of linear and curvilinear relationships in kafir and milo spacing experiments.*

| Year | Kafir: Correlation coefficient, r | Kafir: Sy from straight line | Kafir: Correlation index, Rho | Kafir: Sy from curve | Kafir: Optimum Space, inches | Kafir: Optimum Yield, bushels | Milo: Correlation coefficient, r | Milo: Sy from straight line | Milo: Correlation index, Rho | Milo: Sy from curve | Milo: Optimum Space, inches | Milo: Optimum Yield, bushels | Annual rainfall, inches |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1916 | —0.58±.13 | 2.21 | 0.64±.12 | 2.09 | 9 | 20.1 | 0.34±.17 | 3.31 | 0.83±.06 | 1.96 | 21 | 30.1 | 15.03 |
| 1917 | 0.98±.01 | 0.62 | 0.98±.01 | 0.62 | 36 | 16.1 | 0.76±.09 | 1.52 | 0.93±.03 | 0.54 | 27 | 12.0 | 8.73 |
| 1918 | —0.78±.08 | 1.02 | 0.78±.08 | 1.01 | 3 | 14.5 | 0.92±.03 | 1.07 | 0.94±.02 | 0.92 | 36 | 8.6 | 12.15 |
| 1919 | —0.39±.16 | 3.03 | 0.81±.07 | 1.95 | 3 | 42.2 | 0.09±.19 | 5.19 | 0.42±.16 | 4.72 | 21 | 33.0 | 31.61 |
| 1920 | —0.93±.02 | 2.91 | 0.99±.01 | 1.30 | 3 | 56.9 | 0.73±.09 | 3.33 | 0.87±.05 | 2.41 | 36 | 52.8 | 18.16 |
| 1921 | —0.81±.07 | 2.67 | 0.81±.07 | 2.64 | 3 | 44.6 | 0.58±.13 | 2.14 | 0.61±.12 | 2.08 | 33 | 38.7 | 16.72 |
| 1922 | 0.25±.18 | 1.21 | 0.50±.15 | 1.08 | 21 | 19.6 | 0.77±.08 | 1.44 | 0.84±.06 | 1.20 | 30 | 29.8 | 14.59 |
| 1923 | —0.22±.19 | 2.75 | 0.21±.19 | 2.76 | 3 | 23.4 | 0.76±.08 | 2.67 | 0.90±.04 | 1.80 | 27 | 29.4 | 26.17 |
| 1924 | 0.90±.04 | 0.95 | 0.95±.02 | 0.70 | 36 | 13.8 | 0.72±.09 | 2.38 | 0.94±.02 | 1.15 | 24 | 20.9 | 9.45 |
| 1925 | —0.51±.14 | 3.35 | 0.82±.06 | 2.23 | 3 | 26.6 | 0.45±.16 | 1.04 | 0 53±.15 | 0.98 | 36 | 19.8 | 22.75 |
| 10 yrs. | —0.85±.06 | 0.83 | 0.92±.03 | 0.57 | 3 | 25.5 | 0.84±.06 | 1.15 | 0.90±.04 | 0.83 | 30 | 26.2 | 17.54 |

increases from 6 to 27 inches after which there is again an advance in yield. At this point the plants are apparently so thin on the ground that an appreciably greater number of tillers develop and tend to offset the decline in yield. With milo, the increase in the size of the heads, together with the increase in the number of suckers, tends to increase gradually the yield over the whole range, but the maximum effectiveness of these two forces is reached at 30 inches. In 1919, for instance, spacings of 6, 12, 18, 24, 30, and 36 inches increased progressively in the number of suckers developed, the suckers constituting 10, 21, 37, 60, 63, and 67% of the total stalks, respectively.

In the majority of seasons, a straight line fits the kafir data almost as well as the parabolic curve. Just how much more closely the parabola fits each year's results than does the straight line can be seen by comparing the coefficients of linear and curvilinear relationships in Table 2. As a result of the calculations in fitting a straight line and a second degree parabola to these data, the correlation coefficients and correlation index are readily calculated by formulae. The index of correlation, Rho (3), is essentially slightly higher than the correlation coefficient r, but the difference shown in Table 2 between these two constants is mainly due to the fact that a second degree parabola curve constitutes a better fit to the data than a straight line. Wherever there is a marked difference between the two coefficients, a material reduction in the standard error, or scatter about the line, is also seen.

Coefficients of correlation, calculated by linear and curvilinear methods, are practically identical in 1917, 1918, and 1921 for kafir, but in certain other years, such as 1919, 1922, and 1925, there is clearly non-linearity in the placement or grouping of yield in relation to space between plants. Correlation was in the negative direction in all except three years, in two of which, when the rainfall was extremely low, the yields increased almost directly with a given increase in space between plants. The milo yields each year are better described by the parabola and index of correlation than the kafir yields; however, the correlation is always in the positive direction. Optimum calculated yields for milo are always found toward the upper limits of spacing, whereas, in kafir they usually occur at the lowest. Whenever moisture has been very restricted, the yields of both crops have practically followed a straight line and in the same direction, but in seasons of fair or abundant rainfall the relationship is distinctly non-linear.

## BEARING OF THE RESULTS UPON OTHER EXPERIMENTS

To illustrate the vitiating effect that rate of seeding or spacing in the row can have upon the results of field plat experiments, such

as variety, fertilizer, or other tests, when several varieties are involved, the average yields of varieties discussed herein may be compared. All varieties in field test plats of this kind are usually thinned to an arbitrary distance between plants. When these yields of kafir and milo have been compared in a similar manner, including all the distances of spacing for this 10-year period, the difference in yield of grain per acre has been 1.82 bushels in favor of milo. Had the two varieties been grown only at a 36-inch space between plants, the difference would have been 4.28 bushels, and if an 18-inch space had been employed, the difference would have been 3.45 bushels, both significantly in favor of milo. Compared on a basis of a 12-inch space, the difference is neglible, while at 6 inches there is a difference of 4.61 bushels to the acre in favor of kafir and the conclusions as to the superiority of these two varieties would then have to be reversed.

Twelve inches between plants would seem to be the most nearly comparable spacing when only these two varieties are considered, but this is not the optimum for either kafir or milo. The curves cross at this point (Fig. 3) and, thereafter, as the space between plants increases, an increase is shown in the yields of milo and a decrease in the yields of kafir. Kafir at its optimum spacing of 6 inches averaged slightly under 1 bushel less per acre than milo at its optimum of an 18-inch space. There are undoubtedly genetic differences between these two varieties which give milo an advantage in adjustment commensurate with available moisture. Its ability to compensate the spacing over a relatively wide latitude probably accounts for the popularity of milo in the sorghum area of the Southern Great Plains where there is a quite variable distribution of rainfall.

Engledow's (1) experiments in spacing tests with cereals show a very similar result. Two varieties of wheat, Red Fife and Hybrid H, yielded around 24 bushels and 40 bushels, respectively, under field conditions. When plants were spaced closely Red Fife was more productive than Hybrid H. When given a little more space they were practically equal in yield and at greater distances Hybrid H was the more productive.

When the requirements of row space between plants is so much at variance, as indicated by these two varieties of grain sorghum, accurate comparisons and yields for various varieties and strains can not be obtained from field plat testing at a certain arbitrary and uniform spacing. Probably the most effective means of overcoming this variable would be to group similar varieties in adjacent plats where they may be handled as a unit and thinned to distances between plants which rate of planting tests have indicated to be the optimum for each group.

## SUMMARY

1. Milo has yielded, as an average for 10 years, approximately 21% more grain to the acre, when planted from 18 to 36 inches apart in the row than when planted 3 to 9 inches apart.

2. Kafir, for the same period, has yielded 13% more grain when planted 3 to 9 inches apart in the row than when planted over 18 inches apart.

3. The difference between milo and kafir in response to spacing is accounted for by marked difference in tillering habits. Milo is a profusely tillering variety and kafir a sparsely tillering type. In both varieties the number of tillers increases with the distance.

4. The type of relationship between row space per plant and yield is shown to be curvilinear rather than linear in both crops. In milo the correlation is in a positive direction and normally in the negative direction for kafir.

5. Experiments involving comparisons in which different varieties of grain sorghums are included should take into consideration the variable response to various rates of planting.

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# TESTS OF NATIVE AND FOREIGN CLOVER STRAINS IN WEST VIRGINIA[1]

T. E. Odland and R. J. Garber[2]

This paper is a report of the results of tests of clover strains from various sources, started at the West Virginia Agricultural Experiment Station in the spring of 1925, since work done at other places had indicated the need for information on the comparative value of the different strains for West Virginia conditions. The test plats were located on the agronomy farm at Morgantown, and results from these were supplemented by tests made on farms in several counties in different sections of the state. The results of the county tests were similar to those obtained at Morgantown. The writers wish to acknowledge their indebtedness to Dr. A. J. Pieters of the Office of Forage Crops Investigations who kindly furnished the seed.

Arny[3] in a recent paper in this Journal has reviewed the results of tests with medium red clover conducted in a number of states. Seed of Italian origin has been found to be of little value wherever it has been used. Tests in a number of north central states indicate that French and Chilean strains are little better than Italian for those sections. Noll[4] found that for the conditions obtaining at the Pennsylvania Station, seed of French origin compared favorably with native-grown seed. However, Wolfe and Kipps[5] at the Virginia Station found that seed from France was not satisfactory.

West Virginia is located in the general section of the country where anthracnose is prevalent. Although the winters at Morgantown are not as severe as at some stations where red clover strain tests have been made, the alternate freezing and thawing during the winter causes much damage through heaving, to which the clay loam soil of this region is especially subject. Since the soil is low in organic matter and usually acid, red clover probably has as many disadvantages to cope with in this region as in almost any other section of the country.

[1]Contribution from the Department of Agronomy, West Virginia Agricultural Experiment Station, Morgantown, W. Va. Approved by the Director as Scientific Paper No. 70. Received for publication December 17, 1928.

[2]Associate Agronomist and Agronomist, respectively.

[3]Arny, A. C. The adaptation of medium red clover strains. Jour. Amer. Soc. Agron., 20:557–568. 1928.

[4]Noll, C. F. Red clover for Pennsylvania. Penn. Agr. Exp. Sta. Bul. 200. 1926.

[5]Wolfe, T. K., and Kipps, M. S. Red clover experiments. Va. Agr. Exp. Sta. Bul. 252. 1926.

## METHODS USED

The tests were conducted each year on triplicate 1/80-acre plats. The plats were 66 feet in length and 8¼ feet wide. Alleys 1¾ feet wide separated adjacent plats. The plats were seeded by hand in early spring at the rate of 15 pounds of 90% germinable seed per acre. After the clover was seeded, oats was drilled on the plats at the rate of 1 bushel per acre. The oats was cut for hay before the crop was ripe. The plats were clipped each year in the early fall and the clipped clover left on the ground. Perfect stands, as nearly as could be estimated, were secured on all plats each year.

Notes on the estimated stand of clover were taken in the spring of each year. An estimate was also made before each cutting of the relative amount of anthracnose present. The relative amount of weeds included in the yield from each plat was also estimated.

The clover plats were cut twice each year and the hay weighed after it was field cured. Shrinkage samples were taken when the hay was weighed. These samples were dried in the drying house and the yield on a dry basis calculated from these samples. The yields reported should be increased by about 15% to get yields of hay of average moisture content. The samples contained about 2% of moisture after going through the drying house.

## RESULTS OF TESTS

### RESULTS IN 1925–26

The results obtained in 1925–26 are given in Table 1. The season was rather dry so that the yields are below the average.

The amount of winterkilling was the most severe in the English and the Chilean strains. Although the native strains from Ohio and Idaho showed a high percentage of winterkilling, the surviving plants were apparently much more vigorous than the surviving plants of the foreign strains as indicated by the yields and the small amount of weeds in the hay.

The figures in this table show that the native strains from Wisconsin, Idaho, Ohio, Tennessee, and Michigan yielded more hay which was more nearly free from weeds than any of the imported strains. The Oregon seed in this year yielded about the same as the two strains from France. The strains from England, Chile, Roumania, Hungary, and Italy all produced low yields with a large percentage of weeds. The anthracnose injury was especially noticeable on these strains. The second crop was very poor and much disease was present in all plats from imported seed.

TABLE 1.—*Winterkilling, percentage of weeds in hay, and yields in tons per acre of clover strains from various sources grown at Morgantown, W. Va., in 1926.*

| Source | Strain No. | Winter-killed % | Estimated weeds in hay 1st cutting % | Estimated weeds in hay 2nd cutting % | Yields in tons per acre (dry weight) 1st cutting | Yields in tons per acre (dry weight) 2nd cutting | Total |
|---|---|---|---|---|---|---|---|
| Wisconsin........ | 2410 | 7 | 3 | 1 | 0.97 | 0.75 | 1.72 |
| Idaho........... | 2407 | 33 | 6 | 2 | 0.92 | 0.56 | 1.48 |
| Ohio............ | 2471 | 29 | 5 | 2 | 0.81 | 0.60 | 1.41 |
| Tennessee........ | 2469 | 7 | 4 | 3 | 0.73 | 0.64 | 1.37 |
| Michigan (checks) | 2501 | 19 | 5 | 3 | 0.78 | 0.54 | 1.32 |
| France.......... | 2411 | 27 | 7 | 10 | 0.71 | 0.36 | 1.07 |
| France.......... | 2504 | 30 | 28 | 32 | 0.61 | 0.39 | 1.00 |
| Oregon.......... | 2474 | 27 | 11 | 9 | 0.62 | 0.38 | 1.00 |
| England......... | 2453 | 47 | 36 | 53 | 0.53 | 0.34 | 0.87 |
| Chile............ | 2436 | 42 | 15 | 33 | 0.47 | 0.25 | 0.72 |
| Roumania....... | 2423 | 33 | 10 | 13 | 0.45 | 0.24 | 0.69 |
| Hungaria........ | 2413 | 28 | 10 | 15 | 0.41 | 0.26 | 0.67 |
| Italy............ | 2424 | 28 | 12 | 50 | 0.46 | 0.13 | 0.59 |

## RESULTS OF TESTS IN 1926–27

The data obtained in 1926–27 are given in Table 2. In the second year of these tests the strains of clover from Europe and Chile showed a relatively high percentage of winterkilling and much lower yields than the native strains. The strains from Europe and Chile averaged

TABLE 2.—*Winterkilling, estimated percentage of weeds in hay, and yield in tons per acre of red clover strains from various sources gorwn at Morgantown, W. Va., in 1927.*

| Source | Strain No. | Winter-killed % | Estimated weeds in hay 1st cutting % | Estimated weeds in hay 2nd cutting % | Yield in tons per acre (dry weight) 1st cutting | Yield in tons per acre (dry weight) 2nd cutting | Total |
|---|---|---|---|---|---|---|---|
| Ohio............ | 2582 | 0 | 7 | 7 | 1.23 | 1.09 | 2.32 |
| Idaho........... | 2586 | 2 | 8 | 7 | 1.18 | 1.05 | 2.23 |
| Michigan (check). | 2570 | 1 | 6 | 7 | 1.19 | 1.02 | 2.21 |
| Wisconsin........ | 2610 | 2 | 7 | 7 | 1.19 | 1.01 | 2.20 |
| Tennessee........ | 2469 | 0 | 4 | 5 | 1.07 | 1.10 | 2.17 |
| Oregon.......... | 2567 | 1 | 7 | 10 | 1.17 | 0.98 | 2.15 |
| Chile............ | —— | 12 | 20 | 30 | 0.86 | 0.41 | 1.27 |
| France.......... | 2504 | 27 | 50 | 63 | 0.60 | 0.58 | 1.18 |
| Roumania....... | 2423 | 11 | 20 | 28 | 0.76 | 0.40 | 1.16 |
| Hungaria........ | 2413 | 15 | 37 | 47 | 0.80 | 0.33 | 1.13 |
| France.......... | 2584 | 33 | 42 | 47 | 0.57 | 0.52 | 1.09 |
| England......... | 2554 | 17 | 20 | 37 | 0.57 | 0.40 | 0.97 |
| Italy............ | 2551 | 40 | 73 | 88 | 0.53 | 0.43 | 0.96 |

about one-half the yield of the native strains. As is shown by the estimated percentage of weeds, the hay obtained from the plats seeded with foreign strains consisted to a large extent of weeds. This was particularly true of the second cutting. The strain from Oregon did not winterkill more severely than other native strains in this year and yielded practically the same as the other native strains.

A good second crop of clover was obtained from all native strains, whereas all foreign strains produced a poor second crop. The weights of the second crop of the foreign strains are misleading due to the high percentage of weeds which were included. Before the second cutting there was a large percentage of anthracnose on all plats seeded with foreign strains.

## RESULTS OF TESTS IN 1927–28

The yields and other data obtained in 1927–28 are shown in Table 3. Again in 1928 the clover strains from Europe and Chile show less winterhardiness than any of the native strains, except the one from Oregon. They also yielded considerably less than the native strains. An average of only about 3% of the clover plants on the Italian seed plats survived the winter. No yield determinations were made on these plats for that reason. The Oregon strain showed less winterhardiness in this year than other native strains and yielded somewhat less. All foreign strains were heavily damaged by anthracnose.

TABLE 3.—*Winterkilling, estimated percentage of weeds in hay, and yield in tons per acre of red clover strains from various sources grown at Morgantown, W. Va., in 1928.*

| Source | Strain No. | Winter-killed % | Estimated weeds in hay: 1st cutting % | 2nd cutting % | Yields in tons per acre (dry weight): 1st cutting | 2nd cutting | Total |
|---|---|---|---|---|---|---|---|
| Ohio | 14121 | 7 | 3 | 10 | 1.15 | 1.33 | 2.48 |
| Michigan (check) | 14118 | 8 | 7 | 19 | 1.24 | 1.05 | 2.29 |
| Tennessee | 2640 | 5 | 3 | 7 | 0.96 | 1.20 | 2.16 |
| Wisconsin | 14126 | 2 | 4 | 12 | 0.96 | 1.05 | 2.01 |
| Idaho | 14120 | 2 | 4 | 10 | 0.92 | 1.07 | 1.99 |
| Oregon | 14266 | 25 | 18 | 57 | 0.92 | 0.82 | 1.74 |
| Roumania | 2661 | 10 | 28 | 80 | 0.93 | 0.34 | 1.27 |
| Hungaria | 2667 | 20 | 38 | 80 | 0.93 | 0.34 | 1.27 |
| Chile | 2658 | 83 | 57 | 80 | 0.88 | 0.30 | 1.18 |
| France | 2683 | 40 | 35 | 85 | 0.84 | 0.31 | 1.15 |
| France | 2684 | 88 | 73 | 93 | 0.78 | 0.24 | 1.02 |
| France | 2509 | 43 | 23 | 85 | 0.90 | 0.00 | 0.90 |
| Italy | 2688 | 97 | 98 | 98 | — | — | — |

The native strains produced a second crop which, on the average, was fully as large as the first crop. The second crop from all foreign seed plats was negligible, however, when the high percentage of weeds is taken into consideration. Anthracnose was again prevalent on all foreign seed plats before the second cutting.

## SUMMARY OF THREE-YEAR TEST

In Table 4 the averages from the three years of the tests are assembled. The average estimated winterkilling in the strains from Ohio, Wisconsin, Michigan, Idaho, and Tennessee was 10.2%; Oregon, 18%; Chile, 46%; France, 41%; and Italy, 55%. In the five first-named native strains the estimated amount of weeds in the first crop of hay averaged from 4 to 6% and from 5 to 10% in the second cutting. The Oregon strains averaged 12% weeds in the first cutting and 25% in the second. The estimated amount of weeds in the first cutting of the foreign seed strains ranged from 19 to 61% and for the second cutting from 40 to 79%. The average yield of the leading five native strains ranged from 1.90 tons to 2.07 tons per acre. The Oregon strain averaged 1.63 tons and the foreign strains from 0.52 to 1.06 tons per acre. The average yields show clearly the superiority of native-grown seed.

TABLE 4.—*Average percentage of winterkilling and of weeds in hay and yields in tons per acre of clover strains from various sources grown at Morgantown, W. Va., 1926–28.*

| Source | Number years in test | Total number plats for test | Average winter-killed | Average weeds in hay 1st cutting | 2nd cutting | Average yield in tons per acre (dry weight) 1st cutting | 2nd cutting | Total |
|---|---|---|---|---|---|---|---|---|
| | | | % | % | % | | | |
| Ohio | 3 | 9 | 12 | 5 | 6 | 1.06 | 1.01 | 2.07[1] |
| Wisconsin | 3 | 9 | 4 | 5 | 7 | 1.04 | 0.94 | 1.98 |
| Michigan (check) | 3 | 30 | 9 | 6 | 10 | 1.07 | 0.87 | 1.94 |
| Idaho | 3 | 9 | 12 | 6 | 6 | 1.01 | 0.89 | 1.90 |
| Tennessee | 3 | 9 | 4 | 4 | 5 | 0.92 | 0.98 | 1.90 |
| Oregon | 3 | 9 | 18 | 12 | 25 | 0.90 | 0.73 | 1.63 |
| Chile | 3 | 9 | 46 | 31 | 48 | 0.74 | 0.32 | 1.06 |
| France | 3 | 21 | 41 | 37 | 59 | 0.72 | 0.34 | 1.06 |
| Roumania | 3 | 9 | 18 | 19 | 40 | 0.71 | 0.33 | 1.04 |
| Hungaria | 3 | 9 | 21 | 28 | 47 | 0.71 | 0.31 | 1.02 |
| England | 2 | 6 | 32 | 28 | 45 | 0.55 | 0.37 | 0.92 |
| Italy | 3 | 9 | 55 | 61 | 79 | 0.33 | 0.19 | 0.52 |

## SUMMARY AND CONCLUSIONS

Tests with strains of medium red clover seed from various sources were conducted on the agronomy farm near Morgantown, W. Va., over a period of three years. Native strains from Ohio, Wisconsin, Michigan, Idaho, Tennessee, and Oregon and foreign strains from Chile, France, Roumania, Hungary, England, and Italy were used.

The results obtained show that the clover strains of Italian origin were worthless for the conditions obtaining in West Virginia generally. The strains from the other European countries and Chile in this test suffered heavy winterkilling, produced poor yields, and were generally undependable and of little value.

Uniformly good results were obtained with strains of clover from Ohio, Wisconsin, Michigan, Idaho, and Tennessee. These strains withstood the winters well and produced good crops from both the first and the second cuttings. The strains from Oregon did not do as well on the average under these conditions as the other native strains. The tests show that clover seed obtained from any of the foreign sources included in this test is very unreliable for West Virginia conditions and should not be used.

# THE PERCENTAGE OF NITROGEN IN DIFFERENT PARTS OF SOYBEAN PLANTS AT DIFFERENT STAGES OF GROWTH[1]

LEWIS W. ERDMAN[2]

Chemical analyses of many crop plants show that as a rule the percentage of nitrogen decreases with age, and consequently mature plants contain less nitrogen than young plants. Particularly is this true for plants belonging to the *Gramineae*. In the case of the *Leguminosae*, however, there is some evidence which shows that, although the percentage of nitrogen decreases during the early stages, the legumes gain in nitrogen during the later stages of growth and are much richer in nitrogen at maturity than the nonlegumes. This condition may be due primarily to the fact that in inoculated legumes there is a general transformation of the nitrogen from the nodules to the seeds of the plant.

Whiting[3] studied the relative percentages of nitrogenous compounds in the tops, roots, and nodules of soybeans at definite periods of growth. All the plants were grown in sand cultures. In one experiment the amount of nitrogen in the nodules increased until the plants were 60 days old. After this there was a marked decrease in nitrogen until the final harvest when the plants were 74 days old. The amount of nitrogen in the roots followed the same general course as that in the nodules. The tops gained in nitrogen up to the time when the plants were 67 days old, but after the next 7 days a very decided decrease in amount of nitrogen was noted. In two other experiments soybean plants were grown and harvested at different stages, the final harvest being made when the plants were 41 and 42 days old, respectively. The tops, roots, and nodules showed successive gains in nitrogen for the various stages, the largest amount being found in the plants representing the final harvest. The plants apparently were not grown long enough to follow any possible transformation of nitrogen from the nodules to the seeds.

[1]Contribution from Soil Bacteriology Laboratories, Iowa Agricultural Experiment Station, Ames, Iowa. Received for publication December 22, 1928.

[2]Formerly Assistant Chief in Soil Bacteriology, Iowa Agricultural Experiment Station, and Professor of Soil Technology, University of Maryland. Now Head of The NITRAGIN Company, Inc., Bacteriological Laboratory, Research and Production Departments, Milwaukee, Wis.

[3]WHITING, A. L. A biochemical study of nitrogen in certain legumes. Ill. Agr. Exp. Sta. Bul. 179. 1915.

Piper and Morse[4] reported analyses made by the Bureau of Chemistry of the U. S. Dept. of Agriculture on the chemical composition of soybeans at different stages of growth. The percentage of nitrogen was found to be highest in the roots, stems, and leaves when the plants were in full bloom. It then steadily decreased and the other analyses indicated that there was a transformation of nitrogen from the roots, stems, and leaves to the seeds. It was not stated whether the plants were inoculated or if the roots contained nodules and were analyzed as a whole.

Metzger, Holmes, and Bierman[5] studied the production, composition, and feeding value of soybeans, the main object of their work being to determine what stage in the growth of soybeans furnished the maximum value of the hay without sacrificing any of its palatability. Hollybrook and Wilson soybeans were harvested at various stages of growth and analyzed for nitrogen as well as other chemical constituents. It was found that the Hollybrook soybeans contained more protein in the early stages of growth than the Wilson soybeans, but that when the plants reached maturity the latter variety was richer in protein. For both varieties the plants maintained a constant lower protein level from the time the first blossoms appeared until the beans began to ripen. A distinct increase was then noted for the 120- and 130-day periods.

The object of this paper is to present the results of a study which shows the relation between the percentage of nitrogen in soybean nodules and that found in the roots and tops at different stages of growth.

## EXPERIMENTAL

The material used for this study was collected at different intervals from a number of plats in the 1926 soybean inoculation experiments at the Iowa Agricultural Experiment Station. Four varieties of soybeans were used, *viz.*, Manchu, Dunfield, Midwest, and Peking. At each sampling enough plants of each variety were dug to furnish approximately 100 grams of fresh nodules. This required from 50 to 100 plants each time. The nodules were stripped from the roots, and all but 10 representative plants were discarded. The first samples were taken when the plants were about 60 days old. Other samples were taken at irregular periods of time until the plants from each variety had reached maturity. The samples were separated into tops,

[4] PIPER, C. V., and MORSE, W. J. The Soybean. New York: McGraw Hill Book Co. Inc. 1923.

[5] METZGER, J. E., HOLMES, M. G., and BIERMAN, H. Soybeans—production, composition, and feeding value. Md. Agr. Exp. Sta. Bul. 277. 1925.

TABLE 1.—*Percentage of nitrogen in tops, roots, and nodules of four varieties of soybeans at different stages of growth.*

| Sample No. | Date samples were taken | Manchu Percentage of nitrogen | | | Dunfield Percentage of nitrogen | | | Midwest Percentage of nitrogen | | | Peking Percentage of nitrogens | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Tops | Roots | Nodules | Tops | Roots | Nodules | Tops | Roots | Nodules | Tops | Roots | Nodule |
| A | August 25, 1925 | — | — | 4.87 | — | — | 4.91 | — | — | — | — | — | — |
| B | Sept. 25, 1925 | — | — | — | — | — | — | — | — | 3.71 | — | — | 3.75 |
| 1 | July 28, 1926 | 2.74 | 0.83 | 5.52 | 2.62 | 0.92 | 5.24 | 2.69 | 0.87 | 4.46 | 2.95 | 0.53 | 4.80 |
| 2 | August 20, 1926 | 2.74 | 1.06 | 5.79 | 2.28 | 0.83 | 5.42 | 2.23 | 0.92 | 5.44 | 2.53 | 0.64 | 4.98 |
| 3 | Sept. 2, 1926 | 2.09 | 1.03 | 5.25 | 2.10 | 0.79 | 4.50 | 2.15 | 0.87 | 4.37 | 1.99 | 0.72 | 4.71 |
| 4 | Sept. 28, 1926 | 2.35 | 0.79 | 4.20 | 2.43 | 0.62 | 4.17 | 2.46 | 1.05 | 4.95 | 1.49 | 0.55 | 3.88 |
| 5 | Oct. 10, 1926 | 2.45 | 0.43 | 2.37 | 3.07 | 1.06 | 4.02 | 2.06 | 0.72 | 3.70 | 1.99 | 0.56 | 3.57 |
| 6 | Oct. 13, 1926 | 3.16 | 1.48 | — | 3.03 | 0.76 | 3.59 | 2.42 | 0.58 | 3.75 | 2.35 | 0.86 | 3.55 |
| 7 | Oct. 26, 1926 | — | — | — | — | — | — | — | — | — | 2.25 | 0.76 | 3.18 |

roots, and nodules. These separate parts were thoroughly air-dried in the laboratory after which they were prepared for analysis by grinding very fine. Analyses for total nitrogen were made by the modified Gunning method. The results are presented in Table 1. In the table data are also given showing the percentage of nitrogen

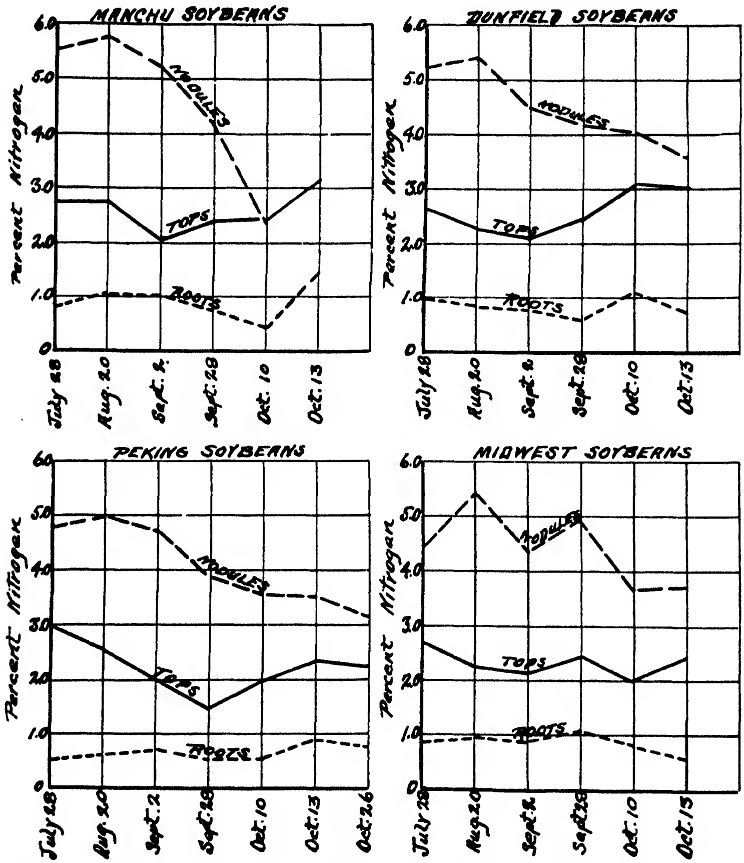


FIG. 1.—Graphs showing percentage of nitrogen in tops, roots, and nodules of Manchu, Dunfield, Peking, and Midwest soybeans at different stages of growth.

found in the nodules from Manchu, Dunfield, Midwest, and Peking soybeans which were grown in 1925. In both years the plants were grown on Carrington loam but in different locations.

For convenience in the interpretation of the results of this study, the 1926 data found in Table 1 have been plotted in the graphs shown in Fig. 1.

## DISCUSSION OF RESULTS

Both of the seed varieties, Manchu and Dunfield, contained practically the same percentage of nitrogen in their nodules on August 25, 1925. The two hay varieties, Peking and Midwest, likewise contained the same percentage of nitrogen in their nodules on September 25, 1925. These dates approximated the time when these varieties would have been cut for hay. It is apparent from the figures that the nodules from the two seed varieties are considerably richer in nitrogen at the hay stage than the nodules from the hay varieties. If the data for similar dates in 1926 are considered for the four varieties, it may be observed that again the nodules from the seed varieties were richer in nitrogen at the hay stage than the hay varieties.

The percentage of nitrogen in the nodules from all four varieties continued to increase after 60 days and reached its maximum on August 20, 1926. It then gradually decreased in the nodules until they began to decompose in the soil. The nodules from Manchu soybeans began to disintegrate a few days earlier than the Dunfield and Midwest soybean nodules and more than two weeks before the Peking nodules. In fact, good sound Peking nodules were found fully two weeks later than nodules of the other varieties.

During the month of September the percentage of nitrogen reached a minimum in the tops from Manchu, Dunfield, and Peking soybeans. In the case of the Midwest soybeans no decided variation in percentage of nitrogen was observed during the entire period of growth.

When the percentage of nitrogen in the nodules from the Manchu, Dunfield, and Peking varieties began to decrease rapidly, the tops showed a decided gain in nitrogen, thus indicating that there was a transformation of nitrogen from the nodules to the seeds. The curves representing the percentage of nitrogen in the nodules and in the tops approached a common point for the Dunfield and Peking varieties. On October 10, 1926, the nodules and tops from the Manchu soybeans contained practically the same percentage of nitrogen. On October 13 the Manchu nodules had started to decompose badly and sampling was impossible.

With the two seed varieties the percentage of nitrogen was higher in the tops at maturity than in the earlier stages of growth, but with the two hay varieties the percentage of nitrogen was higher in the earlier stages of growth.

The percentage of nitrogen in the roots from the four varieties of soybeans showed no marked or consistent variations at the different stages of growth.

## SUMMARY AND CONCLUSIONS

Samples of inoculated soybeans from four varieties grown on Carrington loam under field conditions were collected at various stages of growth. They were divided into tops, roots, and nodules and analyzed for total nitrogen. From this study the following conclusions may be drawn:

1. When seed varieties are cut for hay they contain a higher percentage of nitrogen in their nodules than the regular hay varieties. Seed varieties are richer in protein than hay varieties.

2. As the percentage of nitrogen in soybean nodules decreases there is a corresponding increase in nitrogen in the tops. Thus a transformation of nitrogen takes place from the nodules to the seeds of the plants.

3. In the early growth stages there is a gradual decrease in the percentage of nitrogen in soybean tops, but during September the percentage of nitrogen begins to increase and usually reaches a maximum at maturity.

4. Analyses of soybean plant roots that have been stripped of their nodules show very little variation in percentage of nitrogen during the various stages of growth, thus indicating that the transformation of nitrogen from the nodules is extremely rapid.

# RELATIONS OF GRAZING TO WHEAT SMUT AND TILLERING[1]

H. H. FINNELL[2]

A series of experiments designed primarily to study the effects of seed treatment upon stand and smut control at the Panhandle Agricultural Experiment Station, Goodwell, Oklahoma, has afforded an opportunity for some observations on the effects of seedbed conditions, grazing, and rate of stand upon the amount of stinking smut found in wheat and the tillering of sound and diseased plants. Fifty nursery plats were used in the experiment which consisted of three drill rows each, the plats being 2 feet wide and 10 feet long. The average number of plants per plat was 78.3.

## DERIVATION OF VARIABLES

*Number of plants per plat.*—When harvested, the wheat was pulled up and the plants carefully separated by hand in order to secure a correct count of the number of plants.

*Number of heads per plat.*—In counting the heads per plat, all heads formed were included regardless of whether they contained grain or not. Separate counts were made of smutted and sound plants.

*Soil moisture.*—The moisture was determined from single core samples taken from each plat to a depth of 1 foot. Eight of the block divisions were planted under dry farm conditions in which it will be noted a fairly uniform moisture condition prevailed. Two blocks were irrigated immediately after sowing in order to provide excessive moisture conditions during the germination period.

*Grazing.*—All grazing was done when the topsoil was dry but firm, the soil conditions being considered ideal for the permission of grazing with the least damage to stands. In each case the entire block pastured was cropped close to the ground upon the date indicated, care being taken to trample the plats as little as possible.

*Maturity.*—The date of maturity was roughly determined from daily notes covering the maturity period from which a date was selected on which the majority of heads were completely turned in color, although in all cases a few of the younger heads remained green. This was especially the case in those plats where maturity was delayed by pasturing.

[1]Contribution from the Panhandle Agricultural Experiment Station, Goodwell, Oklahoma. Received for publication January 9, 1929.

[2]Director and Agronomist.

## EXPERIMENTAL

Table 1 presents the detailed information by plats from which the studies were made. It will be noted that each block consisting of five plats given a single initial moisture or grazing treatment included three checks or plats sown from untreated seed which were exposed to the spores of stinking smut. Two plats in each block were sown from the same seed but treated with formaldehyde solution (1 to 560), soaked 10 minutes, and dried in a thin layer; or with a dust application of copper carbonate (50% copper) at the rate of 4 ounces per bushel. All plats were seeded December 11, 1924, on a uniform block of silty clay loam soil.

TABLE 1.—*Stinking smut and tillering of winter wheat under various seed treatments and field conditions.*

| Plat No. | Seed treatment | Total number per plat: Plants | Heads | Percentage smutted: Plants | Heads | Number heads per plant: Smutted | Sound |
|---|---|---|---|---|---|---|---|
| | Sec. A—Initial Surface Soil Moisture 17.42%—Grazed Apr. 1 | | | | | | |
| 11 | None | 53 | 263 | 13.2 | 11.4 | 4.3 | 5.0 |
| 12 | Formaldehyde | 19 | 195 | 0 | 0 | 0 | 10.3 |
| 13 | None | 100 | 548 | 13.0 | 8.9 | 3.8 | 5.5 |
| 14 | Copper carbonate | 94 | 379 | 0 | 0 | 0 | 4.0 |
| 15 | None | 47 | 229 | 17.0 | 16.2 | 4.6 | 4.9 |
| | Sec. B—Initial Surface Soil Moisture 17.51%—Not Grazed | | | | | | |
| 21 | None | 57 | 266 | 10.5 | 10.1 | 4.5 | 4.7 |
| 22 | Formaldehyde | 19 | 293 | 0 | 0 | 0 | 15.4 |
| 23 | None | 61 | 489 | 9.8 | 9.6 | 7.8 | 8.0 |
| 24 | Copper carbonate | 96 | 485 | 0 | 0 | 0 | 5.0 |
| 25 | None | 80 | 323 | 7.5 | 13.3 | 7.1 | 3.8 |
| | Sec. C—Initial Surface Soil Moisture 17.24%—Grazed May 9 | | | | | | |
| 31 | None | 67 | 341 | 7.5 | 3.5 | 2.4 | 5.3 |
| 32 | Formaldehyde | 22 | 215 | 0 | 0 | 0 | 10.2 |
| 33 | None | 105 | 512 | 9.5 | 5.8 | 3.0 | 5.1 |
| 34 | Copper carbonate | 150 | 592 | 0 | 0 | 0 | 3.9 |
| 35 | None | 106 | 378 | 10.4 | 9.3 | 3.2 | 3.4 |
| | Sec. D—Initial Surface Soil Moisture 17.98%—Grazed Apr. 1 | | | | | | |
| 41 | None | 79 | 287 | 7.7 | 9.8 | 4.7 | 3.5 |
| 42 | Formaldehyde | 57 | 265 | 0 | 0 | 0 | 4.6 |
| 43 | None | 132 | 605 | 21.2 | 12.6 | 2.7 | 5.1 |
| 44 | Copper carbonate | 113 | 545 | 0 | 0 | 0 | 4.8 |
| 45 | None | 64 | 388 | 20.3 | 7.0 | 2.1 | 6.5 |
| | Sec. E.—Initial Surface Soil Moisture 17.20%—Not Grazed | | | | | | |
| 51 | None | 102 | 330 | 19.6 | 15.4 | 2.5 | 3.4 |
| 52 | Formaldehyde | 41 | 289 | 0 | 0 | 0 | 7.0 |
| 53 | None | 150 | 446 | 16.0 | 15.2 | 2.6 | 3.3 |
| 54 | Copper carbonate | 115 | 509 | 0 | 0 | 0 | 4.4 |
| 55 | None | 76 | 391 | 19.7 | 21.7 | 5.6 | 5.0 |

TABLE 1.—*Concluded.*

| Plat No. | Seed treatment | Total number per plat Plants | Heads | Percentage smutted Plants | Heads | Number heads per plant Smutted | Sound |
|---|---|---|---|---|---|---|---|
| | Sec. F—Initial Surface Soil Moisture 17.78%—Grazed Apr. 26 | | | | | | |
| 61 | None........... | 50 | 206 | 8.0 | 7.3 | 3.7 | 4.1 |
| 62 | Formaldehyde... | 60 | 199 | 0 | 0 | 0 | 3.3 |
| 63 | None........... | 90 | 385 | 7.8 | 7.0 | 3.9 | 4.3 |
| 64 | Copper carbonate | 150 | 525 | 0 | 0 | 0 | 3.5 |
| 65 | None........... | 95 | 289 | 9.5 | 8.6 | 2.8 | 3.1 |
| | Sec. G—Initial Surface Soil Moisture 18.08%—Not grazed | | | | | | |
| 71 | None........... | 66 | 156 | 7.6 | 5.8 | 1.8 | 2.4 |
| 72 | Formaldehyde.... | 31 | 156 | 0 | 0 | 0 | 5.0 |
| 73 | None........... | 132 | 463 | 14.4 | 13.4 | 3.3 | 3.5 |
| 74 | Copper carbonate | 150 | 466 | 0 | 0 | 0 | 3.1 |
| 75 | None........... | 82 | 438 | 17.1 | 11.6 | 3.6 | 5.7 |
| | Sec. H—Initial Surface Soil Moisture 17.84%—Grazed May 3 | | | | | | |
| 81 | None........... | 31 | 142 | 19.4 | 9.2 | 2.2 | 5.1 |
| 82 | Formaldehyde... | 38 | 201 | 0 | 0 | 0 | 5.3 |
| 83 | None........... | 94 | 498 | 11.7 | 6.8 | 3.1 | 5.6 |
| 84 | Copper carbonate | 106 | 461 | 0 | 0 | 0 | 4.3 |
| 85 | None........... | 120 | 443 | 6.7 | 7.4 | 4.1 | 3.7 |
| | Sec. I—Initial Surface Soil Moisture 25.10%—Not Grazed | | | | | | |
| 91 | None........... | 70 | 392 | 10.0 | 8.2 | 4.6 | 5.7 |
| 92 | Formaldehyde... | 52 | 328 | 0 | 0 | 0 | 6.3 |
| 93 | None........... | 111 | 497 | 20.7 | 11.3 | 2.4 | 5.0 |
| 94 | Copper carbonate | 73 | 304 | 0 | 0 | 0 | 4.2 |
| 95 | None........... | 36 | 136 | 33.3 | 26.5 | 3.0 | 4.2 |
| | Sec. J—Initial Surface Soil Moisture 26.50%—Not Grazed | | | | | | |
| 101 | None........... | 42 | 186 | 5.9 | 13.2 | 10.1 | 4.1 |
| 102 | Formaldehyde... | 70 | 197 | 0 | 0 | 0 | 2.8 |
| 103 | None........... | 73 | 359 | 20.1 | 14.9 | 3.6 | 5.2 |
| 104 | Copper carbonate | 35 | 352 | 0 | 0 | 0 | 10.0 |
| 105 | None........... | 57 | 336 | 3.6 | 3.8 | 5.2 | 5.0 |

TABLE 2.—*Summary of seed treatment results.*

| Number of plats | Seed treatment | Total number per plat Plants | Heads | Percentage smutted Plants | Heads | Number heads per plant Smutted | Sound |
|---|---|---|---|---|---|---|---|
| 30 | None....... | 80.9 | 356.8 | 13.28 | 10.81 | 3.94 | 4.53 |
| 10 | Formaldehyde | 40.9 | 233.8 | 0 | 0 | 0 | 7.02 |
| 10 | Copper carbonate.... | 108.2 | 461.8 | 0 | 0 | 0 | 4.57 |
| 50 | Average all plats...... | 78.3 | 353.5 | – | – | – | 5.03 |

TABLE 3.—*Effect of grazing on tillering, average of all plats.*

| Number of plats | Field conditions | Average number plants per plat | Average number heads per plant Smutted | Sound | Date mature, June |
|---|---|---|---|---|---|
| 10 | Not grazed, high moisture | 61.9 | 4.81 | 5.25 | 20 |
| 15 | Not grazed, low moisture | 83.8 | 4.31 | 5.31 | 20 |
| 10 | Grazed April 1 .......... | 75.8 | 3.70 | 5.42 | 20 |
| 5 | Grazed April 26 ......... | 89.0 | 3.36 | 3.66 | 20 |
| 5 | Grazed May 3 ........... | 77.8 | 3.13 | 4.80 | 25 |
| 5 | Grazed May 9 .......... | 90.0 | 2.86 | 5.58 | 29 |

## SEED TREATMENT

The results from seed treatment are briefly summarized in Table 2 in which the 50 plats are divided on the basis of treatment without regard to soil moisture and pasturage. This division provides an equal number of each of the variously pastured plats for each seed treatment. Smut control was complete with both treatments used and the stands secured were typical of many other similar experiments demonstrating the germination injury from formaldehyde treatment and the seedbed protection from copper carbonate dust. There is a tendency toward an increased number of tillers per plant on the formaldehyde treated plats due to the wide spacing afforded by the very poor stand secured. Though the number of plants secured per plat was significantly greater on the copper carbonate treated sowings, the negative correlation between thickness of stand and number of tillers per plant is not carried out among the heavier stands secured on both untreated and copper carbonate treated plats. This correlation for the entire group, including all treatments, is $-0.4775 \pm .05$, which is a significant relationship but hardly representative of as much as one-fourth of the total influence determining tillering.

## TILLERING OF SOUND AND DISEASED PLANTS

Table 3 presents a summary of the entire data in which plats of all seed treatments are grouped together under the heads of soil moisture and pasturage variables. The means of the plant numbers per plat show some variability in this grouping, but in view of the barely significant correlation just cited probably not enough to affect greatly the determination of tillering. It will be noted that the number of heads per plant, either sound or diseased, agreed closely in non-grazed groups, indicating that probably the initial moisture had little to do with tillering. Grazing up to the date of April 1

apparently did not affect the number of tillers per sound plant. Spring growth had just begun at this time and the plats would not have afforded a very great carrying capacity of livestock.

On the next date of grazing, April 26, a good growth had been obtained. The wheat being from 3 to 5 inches high was capable of affording as much pasturage as could ordinarily be obtained at any time during the wheat-grazing season. A careful examination showed that the shoots had begun to form but in no case had appeared above the ground. The relatively large decrease in average number of tillers per plant in this case is significant. This seems to have been a critical stage in the growth of the plant during which the effect of a sudden removal of the foliage prevented the development of some of the shoots already formed and just about to be put up. The fact that plats pastured on this date matured at the same time as the unpastured plats would seem to indicate that the formation of new shoots did not take place. It must be assumed that the decreased number of tillers per plant indicated only a partial development of those buds already formed.

The next grazing date, May 3, found the wheat with numerous shoots from 1 to 3 inches high which were removed with the foliage cropped close to the ground at this time. This grazing undoubtedly destroyed large numbers of the older shoots, though there must have been many of the more backward tillers left undisturbed. In this instance the date of maturing was five days later than the non-pastured and early-pastured groups, indicating that the crop consisted partially at least of new shoots which were formed after grazing to take the place of those destroyed. A slight increase in the number of culms per plant took place under these conditions over the next previous grazing.

The effects of a later grazing, when the wheat was cropped to the ground after shoots 4 to 5 inches high had developed, gave a similar further delay in date of maturing and an increase in the number of tillers per plant, bringing this figure up to about the same level as that observed in non-grazed plats. The date of maturity of the plats grazed on May 9 was nine days later than the non-grazed and early-grazed groups. It seems probable that almost an entirely new start had to be made by the plant grazed on this last date, since practically all of the shoots had reached a size that exposed them to complete or partial destruction by grazing. It could not be observed whether the early development of diseased plants was slower or faster than the sound ones. It is noticeable, however, that the same response to dates of grazing did not take place with the infected

plants. Beginning with the earliest grazing date there is a steady decline in the number of heads formed per smutted plant. The only explanation of this that has been suggested is that the diseased plants when the setback incident to grazing occurred did not possess the same ability to form new shoots as the sound plants.

## EXTENT OF SMUT INFECTION

The extent of infection is probably best represented by the percentage of smutted plants, although this is shown by Table 4 to be quite variable in the groups studied. In the light of the present information on the mechanism of infection, it could not be understood why grazing would affect the percentage of smutted plants unless it be that some of those present were in such a weakened condition due to the

TABLE 4.—*Relation of grazing to stinking smut, average of non-treated plats.*

| Number of plats | Field conditions | Percentage smutted Plants | Percentage smutted Heads | Date mature, June |
|---|---|---|---|---|
| 6 | Not grazed, high moisture | 20.10 | 12.98 | 20 |
| 9 | Not grazed, low moisture | 13.57 | 12.90 | 20 |
| 6 | Grazed April 1 | 15.40 | 10.98 | 20 |
| 3 | Grazed April 26 | 8.43 | 7.63 | 20 |
| 3 | Grazed May 3 | 12.60 | 7.80 | 25 |
| 3 | Grazed May 9 | 9.10 | 6.20 | 20 |

presence of disease that they were either killed outright or subdued by grazing to a point resulting in the stoppage of all further development of shoots. Under the conditions of this experiment plants could have thus existed on the plats without having been counted. The tendency indicated by these results suggests some such probability. On the other hand, when the smut infection is measured by percentage of heads there is a rather consistent decrease in smut toward the late grazing. This is mainly accounted for by the decreased number of heads formed by smutted plants when grazed late. The increased smut infection obtained on the wet plats as measured by the percentage of diseased plants corresponds to the accepted relation of soil moisture of seedbed.

## DISCUSSION

The number of plants involved in the experiment was 235 for the smallest grouping used and 3,915 in grand total. This seemed to preclude any question of the reliability of numbers along with the fairly consistent behavior through the progressions cited. The im-

pairment of vigor in diseased plants, as evidenced by the development of fewer culms or none at all, appears to be clearly indicated. However, there are some unanswered questions surrounding the explanation offered for the behavior of sound plants under the various grazing conditions. No determinations of yield were made due to the fact that seasonal conditions were very adverse in 1925 near the close of the season and none of the plats did more than fill very shriveled kernels, many of the heads having ripened immaturely at time of harvest. The tendency for a markedly decreased yield, however, was noticeable on those plats grazed late, corresponding with the results of other wheat-grazing experiments. The absence of any indication of a critical period in diseased plants, such as was suggested as existing in the development of sound plants, necessitates the assumption that the diseased plants are void of any recuperating power, and further, that the number of shoots formed by sound plants indicates the reaction of the plant to various degrees of original bud destruction. The larger number of shoots formed on the late-grazed plats accords with the extent to which the plant had to abandon the normal crop of shoots and substitute an entirely new growth.

## SUMMARY

1. Standard treatments of formaldehyde and copper carbonate controlled stinking smut of hard red winter wheat under conditions that produced in untreated plats 13.28% of smutted plants and 10.81% of smutted heads.

2. Stands of wheat secured from seed treatments were represented by the following average numbers of plants per plat: Untreated, 80.9; formaldehyde treated, 40.9; copper carbonate treated, 108.2.

3. Tillering was encouraged by the very thin stands but did not vary significantly above moderately thick stands in this experiment. The correlation of thickness of stand to tillering was $-0.47 \pm .05$.

4. Excessive seedbed moisture did not influence tillering in either sound or diseased plants

5. Grazing in the early spring growth stage, April 1, did not change the number of heads formed per sound plant but decreased the number formed by smutted plants.

6. Grazing the vegetative growth just prior to shooting of the culms, April 26, markedly decreased the number of heads formed per sound plant. The original crop of shoots was undisturbed but failed to develop the full number. Maturity was not delayed.

7. Grazing after the shoots were 1 to 3 inches high, May 3, required the development of a partially new crop of shoots, delayed maturity five days, and resulted in an increase of tillering over the previous grazing date, but the heads per plant remained below the normal number.

8. Grazing after the shoots were 4 to 5 inches high, May 9, required the development of a full new crop of shoots, delayed maturity nine days, and gave a further increase in heads formed per plant, bringing the number up to that of the unpastured plants.

9. Diseased plants did not respond to the cutting back but showed a steady decline in number of heads formed with later grazing.

10. The percentage of plants infected with stinking smut and producing heads was not affected by early grazing but was slightly reduced by late grazing.

11. The percentage of smutted heads was consistently decreased as the number of heads per smutted plant was lessened by later grazing.

12. The percentage of smutted plants was highest where excessive moisture was present in the soil at germination.

13. The data are taken to indicate that wheat plants infected with stinking smut are void of sufficient recuperative power to put up new shoots to replace fully those destroyed and that in extreme cases they may not produce any heads at all.

14. It is suggested that while sound plants are reduced in total production by late grazing, their response in numbers of replacement shoots formed is in respect to the degree of partial or entire replacement required.

# NOTES

## A SMALL GRAIN NURSERY HARVESTER

One of the chief labor problems in the testing of small grains by the rod-row method is that of harvesting. The general practice of cutting by hand not only is back breaking, but often produces an untidy bundle and leaves a ragged stubble. When accurate gross or straw weights are desired, it is necessary that the grain be cut at an even height from the ground. There is need for a motor-powered cutter for harvesting nursery rows that is light in weight, easily manipulated, and narrow enough to cut out a single rod-row without disturbing the adjacent rows.

FIG. 1.—A front view, showing the harvester in operstion. The dividers pick up leaning gain and keep out grain from adjoining rows.

The machine that was built and used at the Illinois Experiment Station during the past year consists of a ¼ h.p., two-cycle, gasoline engine mounted over a lawn mower of the clipper type. The power is transmitted to the drive shaft of the mower by means of a belt and a system of reducing gears taken from a washing machine. The machine has a 12-inch cutter bar, has a total width of 18 inches, and weighs 130 pounds. It has a metal bottom to catch the grain and to keep dirt and stubble out of the mechanism. The cut grain is supported by a frame of hardware cloth fastened to the two dividers that separate the rows in front of the machine.

The harvester was originally made with two belts travelling along the dividers to pull the grain into the hopper, but since two men were necessary to operate the machine, one to push the machine and one to take out the grain at the end of the row, it was found convenient to dispense with the belts and let the man taking care of the grain walk beside the machine and give the grain a shove back into the hopper occasionally, especially at the end of the row.

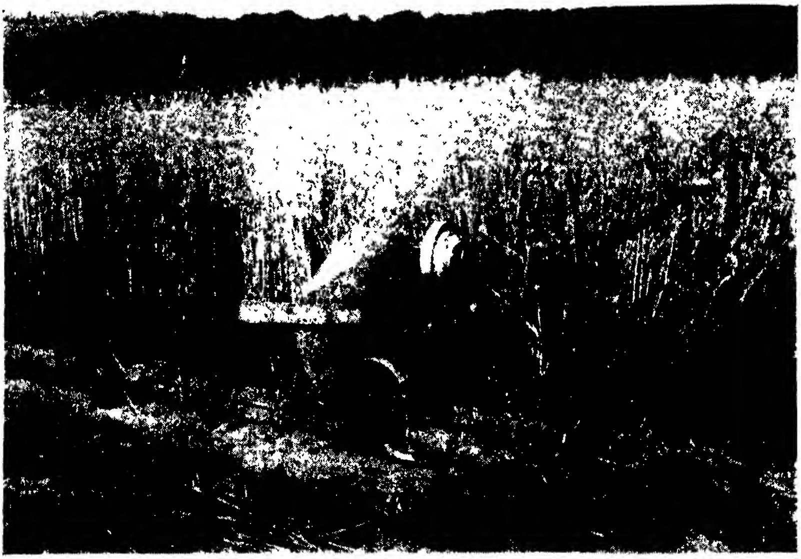

Fig. 2.—A rear view showing method of transmitting power to the cutter.

The machine may be made to pull itself by reversing the dogs in the mower wheels. However, the machine is not hard to push by hand. The operator can choose a speed which will cause the machine to operate the best for the particular row being cut.

The number of rows cut in a given time depends upon the amount of turning that is necessary, the erectness of the grain, and upon whether or not the ripening of the grain will permit it all to be cut at one time.

The machine cut lodged grain considerably faster than two men could cut it by hand. It was tried on rod-rows of soybeans and was found to work as well as it did in small grain.—Floyd L. Winters and Walter J. Mumm, *Department of Agronomy, University of Illinois, Urbana, Ill.*

The breeding work with soybeans being carried on at the Illinois Agricultural Experiment Station makes it necessary to harvest and thresh many plants separately. A thresher was needed that would thresh out the beans without any loss, and at the same time would avoid any mixtures or seed injury.

In building the thresher described here, use was made of a thresher from a Massey-Harris combine which was available and of a suitable size. It had some desirable features. The concave, consisting of bars cast together in a single piece, was held in place by four bolts on each of which was mounted a relief spring that provided a flexible pressure of the concave against material passing through the thresher (Fig. 2). It was possible to change the position of the concave in relation to the cylinder by tightening or loosening the nuts on the bolts that hold the concave in place. The pressure exerted by the concave against the plant could be changed by putting in stronger or weaker springs.

The cylinder, instead of having teeth, was of the corrugated bar type, the corrugations crossing the bars diagonally, the slope of the corrugations being alternately reversed on the bars around the drum. The cylinder was of the usual open type and had to be enclosed. The bars were removed and a strip of heavy galvanized iron exactly the width of the cylinder was fitted around the cylinder and the bars bolted down again to hold it in place. A piece of wood was closely fitted into each end of the cylinder. In the original harvester, the grain had been carried out of the side of the thresher by an augur. This opening had to be plugged and a new opening cut in the bottom.

The opening where the plants were fed in was so large that too many beans were thrown out, even when the hood that originally came with the machine was in place. A fairly stiff strip of metal was cut the width of the inside of the hood. Two loops of metal were soldered to one end of the strip so that it could be hinged. Part of the strip was used to arch the cylinder more completely and the remainder was turned up to help form a flexible opening so that bushy plants could be fed into the machine more easily. The dotted line in Fig. 1 indicates the position of the metal strip and the arrow indicates the feeder opening. A heavy wire, running across the hood, helps support the strip at the inner end. To examine the machine for lodged beans or pods, this strip can be pulled back out of the way, exposing the top of the cylinder.

Occasionally a bean or an entire pod was found lodged behind the concave. To prevent this, the piece of metal to which the concave

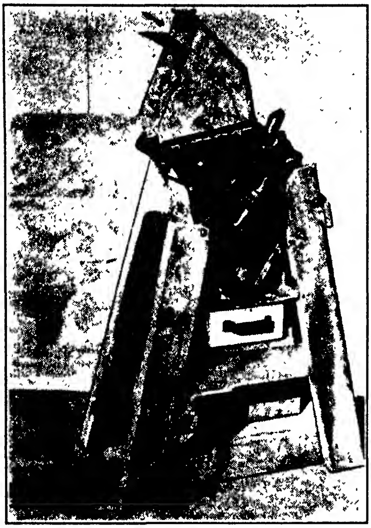

Fig. 1.—Side view of entire thresher, showing feeder opening and grain pan with its cover.

was bolted was cut off and riveted to two heavy hinges. With this change, the concave can be turned back easily at any time for inspection, without stopping the machine, by pulling out a long pin.

One other trouble had to be overcome. When the beans fell into the pan below, many would bounce out. A flat piece of galvanized iron with an opening cut in it the same size as the lower opening of the machine was nailed to the legs of the machine so as to be even with the bottom to serve as a lid over the grain pan.

This machine has no device for cleaning the seed. In practice, the operator retains his hold on the plant he is threshing and pulls the stub and such branches as are not broken off, back out of the feeder. The hulls, dust, and small stems are blown out by a blast from an electric fan.

Very little power is required to operate this machine. At present it is run at a speed of 420 R.P.M., which seems to be fast enough to thresh all the beans. The machine is easily moved, yet it has enough weight so that it need not be fastened to the floor when running.—Walter J. Mumm and Floyd L. Winter, *Dept. of Agronomy, Illinois Agricultural Experiment Station, Urbana, Ill.*

Fig. 2.—Rear view with concave swung open, showing cylinder with ridged bars and concave with spring tension.

# BOOK REVIEW

## LABORATORY MANUAL OF GENERAL MICROBIOLOGY

With special reference to the Microorganisms of the Soil

*By Edwin Broun Fred and Selman A. Waksman. New York: McGraw-Hll Book Company, viii+145, illus. 1928. $2.*

"This laboratory manual has been designed for students in General Microbiology, and especially for those working with soils or with organisms isolated from the soil. Although various exercises are described primarily for students in soils, the methods of isolation and cultivation of bacteria, fungi and actinomyces, algae and protozoa, and the determination of the biochemical activities of these organisms can be used by the student in General and Agricultural Microbiology." (Preface.)

The book is divided into four parts. Part I includes, in addition to a very brief discussion of the "Principles of Microbial Nutrition and Composition of Culture Media for Microorganisms," directions for the preparation of 111 different kinds of media. In many instances reference is given to the publication in which the medium was originally described.

Part II, consisting of 5 pages, is devoted to a discussion of methods of staining bacteria. Part III is given over to qualitative and quantitative methods of analysis, including the preparation of reagents. As indicated by the authors, only a few of the most essential methods are included. These deal largely with the transformations of carbon and nitrogen. Part IV is of particular interest to those who are concerned with soil biology. Fifty-eight exercises are given which include the most recent procedures employed in the study of the micro-organic population of the soil.

To some it may appear that this laboratory manual might have been more helpful to the beginner in bacteriology and especially in soil micro-biology if only those media and analytical methods had been included which the authors had found most effective, giving references only to other procedures.

The brief discussion of principles is presented in a very readable form, while the directions for procedures are clear and concise. The splendid organization of this carefully prepared book commends it to those interested in bacteriology and to soil biologists in particular. (O. H. S.)

# CORRECTION

In next to the last sentence on page 119 of the February, 1929, issue of this JOURNAL reference is made to the effect of lime on "brown" root-rot of tobacco. This should read, "because liming usually increases injury from black root-rot."

# AGRONOMIC AFFAIRS

## PROCEEDINGS OF THE FIRST INTERNATIONAL CONGRESS OF SOIL SCIENCE

The edition of the Proceedings of the First International Congress of Soil Science is off the press and is being mailed out to all advance subscribers. The Proceedings cover approximately 2,700 pages bound in four volumes with paper covers. A small supplemental volume devoted exclusively to the trans-continental excursion is going to press and will be available for distribution at a later date. Members of the International Society of Soil Science who have not already ordered a set of the Proceedings can secure a set by addressing Dr. A. G. McCall, Executive Secretary, Room 119 East Wing, U. S. Department of Agriculture, Washington, D. C. Proceedings are supplied to members at $5.00 for the set and the price to non-members is $10.00. Members who made advance subscriptions will receive a copy of the fifth volume gratis as soon as it is available for distribution.

## NEWS ITEMS

A. M. O'Neal, soil surveyor, Iowa Agricultural Experiment Station, has resigned to accept a position with the Bureau of Chemistry and Soils, U. S. Department of Agriculture. He is to be in charge of investigations on the use of fertilizers for sugar cane and will conduct field experiments in a group of the southern states with headquarters at Houma, La.

John A. Elwell, soil surveyor, Iowa Agricultural Experiment Station, has accepted an industrial fellowship, sponsored by the American Cyanamid Company, at the University of Wisconsin where he will pursue graduate work under Professor Emil Truog.

Arthur H. Eddins, Assistant Pathologist at the Florida Agricultural Experiment Station, received the Ph.D.degree at the Iowa State College in December.

Pedro A. David, on leave of absence from the University of the Philippines, is doing graduate work in crop breeding at the Iowa State College.

F. L. Winter has resigned his position as Associate in Plant Breeding, Department of Agronomy, University of Illinois, effective March 15, 1929, to enter the employ of the Hoopeston Canning Company, Hoopeston, Illinois, in the capacity of Agronomist.

Franklin L. Davis, who completed work for his master's degree at the University of Missouri in 1928, is now Assistant Professor of soils at the North Carolina Agricultural College, Raleigh, N. Car.

## JOURNAL

OF THE

# American Society of Agronomy

VOL. 21 APRIL, 1929 NO. 4

## SYMPOSIUM ON "LIME"

*Leader:* O. S. FISHER, U. S. Dept. of Agriculture.

1. The Portable Soil Laboratory and the Ohio Method of Testing Soils for Acidity. Earl Jones, Ohio State University.
2. Lime Surveys for Use in Illinois and Testing for Lime Requirement. C. M. Linsley, University of Illinois.
3. The Kentucky Marl Beds as a Source of Lime Material. S. C. Jones, University of Kentucky.
4. The Development of Equipment for Dredging Marl from the Michigan Lakes. L. F. Livingston, Michigan State College.

### 1.-THE PORTABLE SOIL LABORATORY AND THE OHIO METHOD OF TESTING SOILS FOR ACIDITY[1]

EARL JONES[2]

Soils and crops specialists of Ohio have long felt the need of some method of making reliable and accurate soil acidity tests in the field. Such tests would enable us to diagnose the farmer's soil problems more accurately than in the past and at the same time make personal contact with the farmer.

The thiocyanate test for soil acidity and a simple test for determining the available phosphorus content of the soil were developed at the Rothamsted Station about 1920. A portable potentiometer that could be used in the field came onto the market about the same time.

[1]Paper read as part of the symposium on "Lime" at the meeting of the Society held in Washington, D. C., November 22, 1928.

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In 1924, E. E. Barnes, formerly in charge of soils extension work in Ohio, devised a laboratory desk that carried all the necessary equipment for these tests and could be transported in a light truck. The desk is unloaded in a garage or under a clump of shade trees and in a few minutes the two men who go with the laboratory are ready for the soil samples.

A systematic plan for advertising the laboratory has been developed. It is not taken into a community unless the local people are interested and have promised to work on the proposition. The local leaders of the project send the names of interested farmers to the county extension agent. If the names do not come in satisfactorily, the county extension agent must do some extra work with the leaders of the lagging community.

Directions for taking samples and other necessary information is sent to the farmers who signed the cards. Two or three letters are sent so that the farmer will have no chance to forget about the proposition. This information is also published in the local papers and given publicity in other ways so that all interested farmers may be reached. The farmer is urged to bring rather than send his samples, since a personal interview with him is essential to the success of the proposition.

The county extension agent registers the samples brought to the laboratory. The soil type is recorded where possible. Otherwise the texture and color are noted. The deficiencies in crop growth, the rotation to be followed in the future, the manure available for use etc., are also recorded.

The tests are explained, and the farmer is advised to follow his samples through the laboratory. His attention is called to a colored pH chart. The red color developed by acid soils in the thiocyanate acidity test and the color or absence of color in the available phosphorus test make a decided visual impression on him.

Before making recommendations for soil treatment the farmer's practices in regard to drainage, rotations, seeding mixtures, and the use of fertilizers and liming materials are checked. Recommendations for changes are made when the present practices are not considered satisfactory. Special attention is given to the question of liming for the legume that is to be seeded. The recommendations for the use of the "Standard Ratio Fertilizers for Ohio" are followed in recommending fertilizer treatment for the crops to be grown. The money crop is given first consideration in the fertilization of the rotation. The use of liming materials or tile drainage may, for the present, be more important than larger applications of fertilizer.

The personal interview with the farmer is a very important part of the project. Good seed potatoes may be more important, for the present, than more fertilizer. A prejudice against a new practice may stand in the way of improvement. An example is the idea that corn should never be fertilized in the hill or row. The specialist endeavors to outline a complete system of soil and crop management for the rotation.

Follow-up letters are sent to the farmers who visit the laboratory. A letter discussing the fertilization of corn and oats and the spring use of liming materials is prepared in the winter, while the fertilization and liming of wheat is discussed in a summer letter. Letters are sent to those who have special problems like the improvement of permanent pastures, the seeding of sweet clover, etc.

In 1927, the laboratory was scheduled for 136 meetings in 27 counties, and 4,552 soil samples were tested. In 1928, 163 meetings were held in 29 counties, and 5,348 soil samples were tested. In 1927, 1,600 soil samples were brought or sent to the laboratory at the University. The laboratory was taken to the field about the middle of March in 1928 and was busy until November 1, except for the harvest season and the time necessary for setting up the college exhibit for the Ohio state fair. The laboratory is already scheduled for the first half of the 1929 season.

Part of Geauga County was covered by the laboratory in 1927 and the remainder of the county in 1928. The number of soil samples per meeting in 1928 was double that of the previous year. Better methods of advertising were responsible for part of the increase, but there is a growing interest in the laboratory as farmers hear about its work.

The work with the laboratory has brought to the soils specialists much valuable information concerning the soils of Ohio.

The soil types of western Ohio are easily recognized. The laboratory records give us the reaction of many unlimed Crosby, Miami and Brookston soils, together with the performance records of legumes on each soil type.

In northeastern Ohio the soil types are not so easily recognized and most of the cultivated soils have been limed. It is possible to compare the reaction of the soil with the application of liming materials and with the reported growth of legumes. The soils that require heavy applications of liming materials to produce a definite change in the reaction can be roughly located.

We get much interesting information concerning the response of soils to different treatments during the interview with the farmer. We learn of many valuable demonstrations which would otherwise

remain unknown to us. We get the reaction of many farmers to the use of fertilizers. We collect considerable information concerning the results of different applications of liming materials on the growth of various legumes. The success or failure of different drainage systems may also be recorded.

Both the laboratory records and the farmers' reports are of great value in preparing satisfactory recommendations for soil treatment. Both are especially helpful in bringing to our attention the differences between soil types in reaction and their response to applications of liming materials, fertilizer, and drainage.

A project to promote the use of more liming materials cannot be completed with the use of the laboratory or by any other work that the extension specialist may do. The liming materials must be made available to farmers, preferably in the quantity desired and at the most convenient time for each individual farmer.

Investigations have shown that the present system of selling liming materials in Ohio does not meet the requirements listed above. The local agents in Geauga County were visited in the spring of 1928 and their ideas regarding the sale of liming materials were secured. All agreed that the commission from the sale of liming materials is too small to warrant personal calls on all farmers, the extension of credit, or the extensive storage of materials. There is a tendency for the salesmen to concentrate their efforts in the counties where sales are most easily made and to neglect the communities where more effort is necessary.

In five counties in northeastern Ohio where the laboratory has been in operation, salesmen of liming materials have been called into a conference. The results of the acidity tests and the interest that farmers have shown have been presented to them. They are then asked to cooperate in intensive sales efforts in the county and especially in the townships where the laboratory has been set up.

In every case they have promised cooperation and sometimes they have divided the county into districts, so that there will be less lost motion in their sales efforts. Sales reports for 1928 are not yet available, but several county extension agents have reported that they are well pleased with the results and that there have been increased sales in communities which have had little attention in the past.

# 2. LIME SURVEYS FOR USE IN ILLINOIS AND TESTING FOR LIME REQUIREMENT[1]

C. M. LINSLEY[2]

The need for a soil testing project in our extension program became evident several years ago. Although our extension workers had for years emphasized soil acidity and the need for soil testing in our limestone legume program, progress had not been satisfactory. Many farmers were wasting clover seed year after year on land that was too acid to grow this crop successfully, while other farmers were too enthusiastic about limestone, and as a result were liming land that did not need lime. The rank and file of farmers were not correctly informed on the question of soil acidity.

Several points seemed to demand consideration in such a project. These were as follows:

1. The farmer must be educated to a better understanding of the problem of soil acidity.

2. The plan must include the systematic testing and mapping of the field or farm. This was necessary because of the variations in the soil with respect to its lime needs. The soils, even within a single field, will usually vary in their need for lime. Often a field will have areas of sweet, slightly acid, medium acid, and strongly acid soil. A systematic plan of testing and mapping seemed to be necessary to outline the areas with different lime requirements. Previous experience had indicated that the testing of only one or two samples was not sufficient, and might be altogether misleading.

3. Such a project must make it possible to test a large acreage with a minimum of time and labor. Most of the soil testing in the past has been done by the farm advisers. This testing was usually confined to the testing of one or two samples from fields on various farms in the course of their farm visits. Sometimes they were called on to drive many miles for the specific purpose of testing a farmer's field. Although the farm advisers usually test only two or three samples from a field, this service requires too much of their time. Of course, it was out of the question to expect the adviser to offer an extensive and reliable soil testing service to his membership. The solution to this problem seemed to be that the farmer must be taught to test his own soil.

[1]Paper read as part of the symposium on "Lime" at the meeting of the Society held in Washington, D. C., November 22, 1928.

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With these points in view, the Soil Department formulated a project that was designed to teach farmers to test and map their own soil. This project was planned so that it could be carried out by the farm bureaus through the use of project leaders.

## COUNTIES ADOPT SOIL TESTING PROJECT

When a county requests help in its soil program, the soil extension specialist usually suggests that the soils work be started with the project called the "County Program of Soil Management." This project seems especially fitted for the development of soil project leaders. Briefly the plan is as follows:

The farm adviser and his executive committee select and give official appointment to one leader from each township or community in the county. An official appointment of this sort tends to impress these men with their responsibility as leaders. These leaders are then called in to meet with a representative from theUniversity to discuss and formulate a long-time soil program for the county. In practically every county these meetings emphasize soil acidity as one of the fundamental problems that should receive first attention. Other problems, such as the use of sweet clover, phosphate, and potash, are also discussed.

The soil specialist then explains the soil testing project along with other projects as a means of solving some of these problems. The leaders, in deciding which soil project should be emphasized in the soil program of their respective counties for the coming three to five years, have invariably adopted soil testing as the major soil project to be stressed for the first two or three years. When this is done, arrangements are made for a soil testing school for these leaders. The object of this school is to train the leaders in soil testing and mapping, in order that they may help in supervising this work in their own communities. Direction sheets for collecting soil samples from a 40-acre field and envelopes are given the leaders, and they are asked to collect samples to bring to this school.

## SAMPLES COLLECTED SYSTEMATICALLY

The directions call for 23 surface, 5 subsurface, and 5 subsoil samples. On one side of this direction sheet a diagram (Fig. 1) of a 40-acre field shows the farmer how to locate the points at which the samples are to be taken. By means of lines and arrows, indicating distance and direction, the farmer is instructed to walk 44 3-foot paces east from the northwest corner of the field, and then 44 paces south, where he is to collect surface sample No. 1. He then continues 44 paces south for subsurface and subsoil samples No. 1.

Another 44 paces south locates surface sample No. 2. Each of the 23 surface samples, and the 5 subsurface and 5 subsoil samples are located in this manner.

Five trips, at regular intervals, across a 40-acre field are necessary to collect these samples. This usually requires from 1½ to 2 hours. On the reverse side of the sheet, printed instructions give the details of collecting these samples. A tablespoonfull of soil is collected for

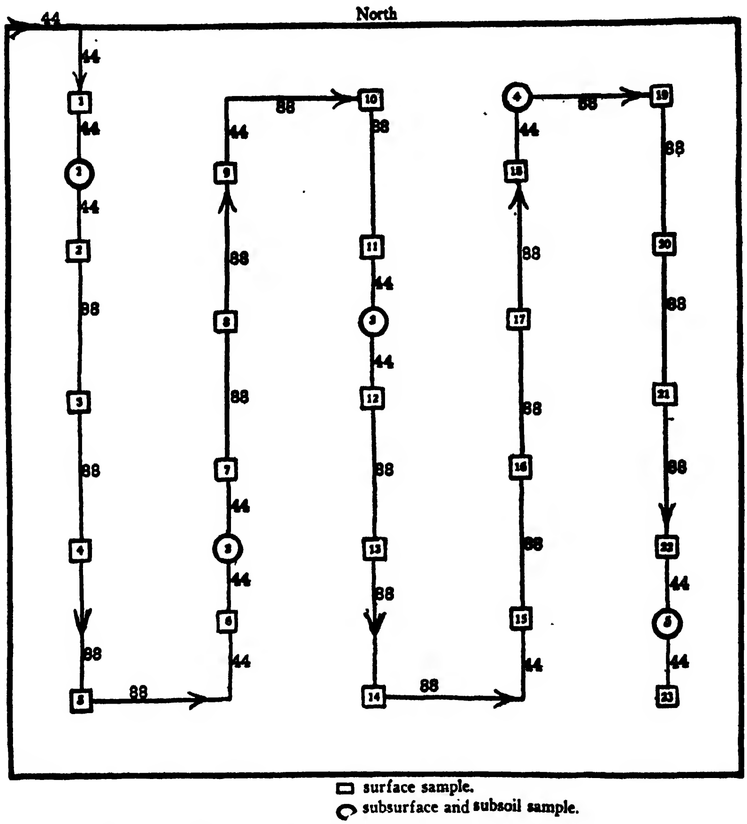


FIG. 1.—Soil sampling diagram for 40-acre field.

each sample. The surface samples are collected from the top 7 inches of soil. Samples are collected from the subsurface and subsoil layers, if these strata are distinct, or if these layers are not easily detected samples are taken at arbitrary depths of 12 and 20 inches, respectively.

Envelopes or small paper sacks are used for collecting. The advantage of envelopes or paper sacks over testing bottles is that

extra soil can be collected for making the carbonate test. Also, if the soil happens to be wet when collected, the samples will dry more thoroughly in the paper container.

## LEADERS LEARN TO TEST SOIL

The leaders' testing schools are held under the supervision of a representative from the University. At the testing school each leader is given a set of 33 testing bottles, or vials. Bottles of 1 to 2 drams capacity are convenient to use for this work. A rack is use2 for convenience in handling and keeping the bottles in order. Such a rack can be made out of a strip of wood about 1 x 1½ x 34 inches by boring 33 holes on inch centers part way through this stick. These holes are bored so that the bottles fit them snugly.

The leaders are instructed in the details of making the Comber test for acidity. They are directed to fill the bottles one-third full of soil and then to add enough potassium thiocyanate solution to fill the bottle about two-thirds full. A complete set of samples can all be shaken at the same time by holding a strip of wood over the corks of the bottles to keep them in place.

After the samples have been allowed to settle, instructions are given in reading the results of the test and in recording these results on a map sheet. The map sheet is numbered to correspond to the direction sheet and to the sample numbers. If sample No. 1 is sweet, No. 1 on the map is either left unmarked or marked with a zero. If sample No. 2 is slightly acid, it is indicated on the map by one dash. If sample No. 3 is medium acid, it is marked with two dashes. If sample No. 4 is strongly acid, it is marked with three dashes. The results of subsurface and subsoil tests are recorded in a space provided at the bottom of the map sheet. The areas of equal degrees of acidity are then traced in with a lead pencil. A red pencil is used to color in the acid areas, using shades of different intensities to indicate the different degrees of acidity. The coloring of the map is important. Although this may seem like a kindergarten exercise, it adds much to the effectiveness of the meeting. In the making of maps of this kind, the farmer is better able to visualize the areas of sweet and acid soil. He can often associate these areas with the topography of the field or with growth of crops, and this does much to make the test convincing.

Two copies of this map are made, one for the farmer and one for the farm bureau. An acidity report card, with space for recording the test of each sample, is also filled out at the time the maps are made and is mailed in to the University. These report cards give some valuable information on the soils of the state, and also keep the specialist informed as to the progress of the work in the various counties.

After the maps are finished, each farmer is called on to explain his map. These explanations often bring out some interesting points. The farmer frequently points out that the uncolored or sweet area on his map is the low ground where he has always had a good stand of clover, or that the acid areas are where his clover has always failed. These observations regarding the maps naturally lead up to a general discussion of soil acidity, limestone, legumes, and other soil problems.

Before the meeting is adjourned, the leaders are instructed in their job of putting over this project. Arrangements are usually made with the leaders at this time for the local soil testing meetings in their respective communities. Whenever possible, a series of these meetings are held within the next two to four weeks. If these local meetings are not held within a reasonable time after the leaders' school, the leaders may lose much of their enthusiasm. A series of meetings makes it possible to use publicity more effectively than is the case when the meetings are scattered throughout the season.

These meetings are held at a time when the farmers are not too rushed with farm work. Probably the most convenient time is the period between threshing and wheat sowing. Successful meetings are often held at some farm conveniently located.

The local project leaders have proved very valuable in arousing interest in this work. They will often call their neighbors on the telephone to explain the object of the soil testing project, and to notify them of the local testing meeting that is to be held in their community. Some carry their map and rack of samples to sales, threshing jobs, or other places where a group of farmers are gathered, or they may put them up as exhibits in prominent banks or store windows in town. Thus, in these and in other ways, the leaders are able to give the project effective publicity.

## FARMERS LEARN TO TEST SOIL AT LOCAL TESTING MEETINGS

The local testing meetings are conducted in much the same manner as the leaders' schools. The farm adviser, with the assistance of the local project leader, instructs the farmer in each step necessary in making the test. When all samples are ready for reading, the farmers are shown how to read and record the results of the test and how to draw in the map. Before the meeting is adjourned, time is taken to discuss the significance of the test of the different fields. This is usually followed by a discussion of some of the important soil problems. The discussion is one of the valuable features of the project. This type of meeting is informal, and for that reason farmers will usually take an active part in the discussion.

After the completion of the series of meetings, county-wide publicity is given to a summary of the soil testing meetings, stressing the significance of the work done. In some counties, the soil testing work may be followed by carefully planned campaigns to encourage the use of limestone, sweet clover, etc.

These testing meetings are repeated in each community for two or three years, in order to give the majority of the farmers instructions in soil testing. After two or three such meetings in each community, the farmer is encouraged to do his own testing without any assistance.

## LARGE ACREAGES CAN BE TESTED

Since this project was started three years ago, 50 counties in Illinois have adopted this soil testing plan. Because of unfavorable weather and a backward season during the past two years, not all were able to carry the project to completion. However, a number of counties have tested from 2,000 to 10,000 acres annually. As a conservative estimate, probably 100,000 acres have been tested according to this plan. One county in central Illinois has carried on this project for the past four years, and during that time has tested and mapped more than 21,000 acres. The results of the testing project in this particular county are as follows:

| Degree of acidity | Acres |
|---|---|
| Sweet | 7,297 |
| Slightly acid | 11,763 |
| Medium acid | 2,317 |
| Strongly acid | 343 |
| Total | 21,720 |

## TESTING PROJECT SAVES MONEY IN LIMESTONE AND CLOVER SEED

The soil testing project has appealed to Illinois farmers. It has meant a saving of a large amount of money in both limestone and clover seed. A typical case of such a saving in limestone is that of a farmer of one of the northern Illinois counties who had planned to apply 3 tons of limestone to the acre on a 40-acre field. When a testing meeting was held in his community, he collected samples from this field according to directions and brought them to the meeting. The results of the test showed him that only 10 acres of the 40 were acid. The remaining 30 acres did not need limestone. This meant a saving of 60 tons of limestone worth $120.00.

That the examination of only one or two samples may be misleading is shown by the case of the farmer who did not believe that it was necessary to go to the trouble of making a systematic test of the

field. The test of samples from the corner of his field indicated that he needed 3 tons to the acre. He ordered 120 tons of limestone, and while the limestone was on the road he was induced to test his field according to the plan of the soil testing project. After he had tested the field and drawn the map, he found that the lime requirement of the field was only 60 tons instead of 120 tons. This represented a saving to him of $90.00, or, as he reminded the farm adviser, the saving was enough to pay his farm bureau dues for the next six years.

Last year Illinois farmers used 730,000 tons of limestone aside from that produced by the local crushers. Where a large annual tonnage of limestone is used, it is important that farmers know where this limestone is needed.

Equally as important as the saving in limestone is the saving in red clover, alfalfa, and especially sweet clover seed. Illinois farmers have become enthusiastic about sweet clover, and the acreage has increased by leaps and bounds. In 1927, there were 619,000 acres of sweet clover grown in Illinois. Unfortunately, many farmers are attempting to grow sweet clover on acid soil.

We often hear farmers admit, "I have thrown away enough high-priced clover seed on my land before I tested it and found that it was acid to have paid for limestone for the whole farm." The testing project is impressing the farmer with the importance of testing his land before he attempts to grow sweet clover and other acid-sensitive legumes.

An example of how this soil testing work has impressed many of our farmers is the case of a farm bureau member who tested his soil at one of the soil testing meetings this fall. His samples had been collected from a field where he had seeded sweet clover last spring and failed to get a stand. The test shows that the entire field was acid. According to his statement, if he had tested this field last year he would have saved $60.00 in sweet clover seed.

Aside from the advantages that have already been mentioned, there is another distinct advantage to this plan of testing. This is the psychological effect on the farmer when he makes the test himself. When the farm adviser or someone else makes this test for the farmer, he may not be much impressed, at least not to the point of buying limestone. It probably appears to him to be some mysterious trick of chemistry. However, this same test in his own hands loses its mystery and becomes a reliable test that tells him whether or not he needs limestone.

# 3. THE KENTUCKY MARL BEDS AS A SOURCE OF LIME MATERIAL[1]

S. C. Jones[2]

The discovery five years ago of the value of calcareous clay or marl deposits found so widely distributed in association with the limestone formations in Kentucky and in old lake beds in Union, Henderson, and adjacent counties along the Ohio River, has resulted in supplying many farmers in the state with a cheap and easily accessible source of lime for use on their soils. To date, marl has been found in greater or smaller quantities in some 70 counties in Kentucky. Of this number, more than half contain deposits of considerable extent.

Although marls were observed in Kentucky by early geologists and their use for improving the soil was suggested, the importance of lime for correcting acid soils was not then fully recognized. Moreover, the geologists of those days were looking for a clay free from lime, suitable for brick, tile, pottery, etc., and therefore gave little attention to clay materials rich in lime.

Kentucky marls are, for the most part, soft, calcareous or calcareous-magnesian shales or soft, calcium limestone or magnesian limestone which, when exposed to the action of weathering agencies, quickly break down into a finely divided condition. These shales and limestones usually are interbedded between more or less massive beds of hard limestone and weather into marl beds varying in thickness from 3 to 60 feet. The old lake marls, however, have apparently never been consolidated into hard material.

The main constituents of marls are calcium and magnesium carbonates, some being more highly magnesian than others. In fact, very few pure calcium marls are found in Kentucky. They also contain small proportions of various other constituents such as sulfur, phosphate, and potash compounds, with considerable proportions of aluminum silicate or clay as a basic material. Much of the marl of the various formations contains lime concretions or fragments of lime rock of varying size.

## MARL FORMATIONS IN KENTUCKY

Marl beds have been found in Kentucky in the following formations named in descending order: The coal-measures, the

[1]Paper read as part of the symposium on "Lime" at the meeting of the Society held in Washington, D. C., November 22, 1928. Contribution from the Department of Agronomy, Kentucky Agricultural Experiment Station, Lexington, Ky. Published with the approval of the Director.

[2]Field Agent in Agronomy.

Chester, St. Genevieve, Waverly, Silurian, Cincinnatian, and Trenton series of rocks; and the ancient lake beds. The Chester, St. Genevieve, and Waverly belong in the subcarboniferous or Mississippian group. The Cincinnatian and Trenton constitute the Ordovician group.

Coal-measures marl has been found in small quantities only in the central part of the western coal fields in connection with limestone occurring above coal No. 11 and probably with the limestone occurring above coal No. 14. This marl is low in neutralizing value, rarely running above 35%, estimated as calcium carbonate.

The Chester formation occurs immediately below the coal-measures and outcrops in the territory surrounding the two coal fields. The formation is thin and of little significance adjacent to the eastern coal field, but is thick and outcrops over probably 3,000 square miles of territory adjacent to the western coal field. Marl beds varying in thickness from 3 to 10 feet occur interstratified with the Chester limestones and shales at various intervals through the Chester formation.

The St. Genevieve formation occurs immediately below the Chester and outcrops in the adjacent territory. Like the Chester, the St. Genevieve formation is developed to a much greater extent around the western coal field and is found in the same counties, and also in some sections where the Chester is not found. In Warren and the adjacent counties in the St. Genevieve formation, marl is found in two horizons in deposits varying in thickness from 6 to 10 feet. The upper bed lies some 30 to 40 feet above the lower, with massive limestone between. They vary in neutralizing value from 50 to 98% estimated as calcium carbonate.

The Waverly marl beds occur for the most part in the Upper Waverly (Harrodsburg) limestone area. The Harrodsburg limestone takes the name from a typical outcropping of this formation at Harrodsburg, Monroe County, Indiana. While the Waverly formation is found in some 25 counties in Kentucky, the Harrodsburg limestone is developed in only about a dozen counties in west central and southern Kentucky.

The thickness of the Harrodsburg formation in Kentucky ranges from a few feet to probably 200 feet or more. Two or more shale beds occur interbedded in the Harrodsburg formation, varying from 10 to 30 feet which, on exposure, weather very readily into a light yellowish or bluish, soft, calcareous, or marly material. They vary in neutralizing value from 25 to 98%, estimated as calcium carbonate.

The Silurian formation is exposed to a greater or less extent in some 24 counties on the border part of the bluegrass region from Lewis County on the Ohio River on the east to Jefferson, Oldham,

and Trimble Counties on the Ohio River on the west, except a section including a part of Marion, all of Boyle, and a part of Lincoln Counties, where the Silurian formation is absent. This formation is made up of beds of limestone containing various proportions of calcium and magnesium carbonates, ranging in thickness, from locality to locality and at different horizons, from a few feet to some 40 feet. These limestones are interbedded with calcareous clay, or marl, beds that range in thickness from a few feet in some sections to as much as 60 feet or more in others.

The most extensive marl beds so far discovered are found in the Silurian formation. In the counties on the west side of the bluegrass region there are two beds of marl, one occurring some 20 to 40 feet above the other. In Jefferson County the upper bed is designated by geologists as the Waldron shale and the lower bed as the Osgood shale. In this county the upper bed is about 12 feet thick and the lower bed about 20 feet thick. Both north and south of Jefferson County in some localities these beds become decidedly thicker. For the most part the richer marls are found in the counties on the west side of the bluegrass region, but extensive beds of rich marl have been found in Lincoln, Garrard, Madison, and Montgomery Counties. The Silurian marls vary in neutralizing value from 30 to 98%, estimated as calcium carbonate.

The Cincinnatian marls occur for the most part in the upper half of the Richmond formation, which is in the upper part of the Cincinnatian. This formation lies immediately below the Silurian and outcrops in the adjacent territory, occurring in places many miles within the Cincinnatian area. The marl beds in the upper Cincinnatian vary in thickness from 4 to 6 or 8 feet and in neutralizing value from 40 to 65%, estimated as calcium carbonate.

Marl occurs in the Trenton formation only in limited quantities. The beds are only 2 or 3 feet thick. Their neutralizing value varies from 65 to 80% of calcium carbonate.

Extensive deposits of old lake marl have been found in Union and Henderson Counties and in limited deposits in Daviess, Hancock, Crittenden, and Livingston Counties. The marl deposits in these counties apparently are remnants of ancient lake beds and probably had their origin in a way very similar to that of the glacial lake marls in Wisconsin, Michigan, and other northern states, having been formed at a much earlier period. They contain more silt and clay than the glacial marls of Michigan and Wisconsin and are therefore much lower in neutralizing value, varying from 25 to 50%, estimated as calcium carbonate.

Calcareous beds of a very similar nature have been found in the deep loess belt in Fulton and Hickman Counties along the Missíssipi River. Practically the same formations occur in some 20 counties in southern Indiana as are found in Kentucky and carry the same marls. Also, the Silurian formation on the east side of the Cincinnatian arch extends north into Ohio.

In a brief survey in Tennessee during January, 1927, marl was found in the Silurian formation in west central Tennessee, the beds, however, being much thinner than those occurring in Kentucky.

Extensive beds of highly calcareous clay or marl were found in the southeastern part of McNairy County, Tennessee. These beds occur in what is shown on the Tennessee geological map as the Selma member of the upper Cretaceous formation. The marl beds in this part of McNairy County, and in Alcorn County, Mississippi, vary in thickness from 20 feet to approximately 100 feet. These marls vary in neutralizing value from 30 to 50%. Geological reports indicate that chalky or marly material occurs in the Selma member of the Cretaceous formation in Tennessee, Mississippi, Alabama, Georgia, and South Carolina.

Extensive beds of a high-grade fresh water or precipitated marl occur in Green, Washington, Sullivan, and probably neighboring counties in eastern Tennessee and Virginia. The marl found in these counties is very different in its origin from that found in other parts of the country. The other marls described above are either of marine or lake origin; that is, the marine marls have been formed under the sea in much the same way as other sedimentary rocks, such as shale, limestone, and sandstone, whereas in eastern Tennessee the precipitated or fresh water marl has been deposited from large springs or veins of fresh water, carrying the lime out of the earth as calcium bicarbonate, which, on exposure to the air, loses carbon dioxide and water, so that calcium carbonate is precipitated, forming marl. These big springs have been depositing marl for thousands of years and in many places acres of material of this nature varying in thickness from 10 to 30 or more feet have been deposited. As a rule, the marl is soft and resembles very much in texture and appearance wood ashes. These marls vary in neutralizing value from 60 to 90%, estimated as calcium carbonate.

## MEANS OF ENCOURAGING FARMERS TO USE MARL

Various methods have been employed to convince Kentucky farmers in the marl territory of the value of marl as a substitute for other forms of lime. Extensive use has been made of publicity

through state and local newspapers, circulars, letters, and posters; also, through exhibits at the state fair, county fairs, and school fairs and in banks and other public places. Various other methods, such as meetings, handling demonstrations, result demonstrations, tours to marl beds, etc., have been extensively used. Yet many farmers have not been convinced that what they designate as "that old white dirt," in which nothing will grow, could be of any value when applied to their land. County agents' reports show the following results as to how marl was used during the past four years:

1924, 138 men in 16 counties used 4,624 tons
1925, 437 men in 24 counties used 9,311 tons
1926, 317 men in 26 counties used 9,317 tons
1927, 243 men in 35 counties used 10,873 tons

Our goal for 1928 is 25,000 tons in the counties having agents.

Many progressive farmers became interested in using marl from the first. From these we have learned much that has been of great value to our extension forces in promoting our marl work. Giltner Brothers, who own a number of farms in Henry and Shelby Counties containing extensive beds of marl, were the first farmers to make extensive use of the stationary chute or inclined plane for loading marl. This method of loading consists simply of an inclined plane and slip scraper with a rope and pulley for drawing the loaded scraper into a wagon or manure spreader. Either horses or tractor may be used for loading. Giltner Brothers have used a tractor. They say they have used 2,100 tons of "white gold" on their land and claim that with this method they can plow, load, and spread marl when the field is nearby at a cost of 40 cents per ton.

From E. R. Greene of Grayson County, we learned how to load marl with a portable chute, which has really proved to be the most convenient and rapid method of loading marl. The portable chute consists of a gang plank 3½ feet wide and 12 feet long. It is made from planks 1 inch thick nailed on to 2 x 4 battens with 2 x 4's nailed to the sides, leaving ¼ to ½ inch flange to prevent the scraper from sliding off. Two men can easily lift the portable chute on to and off of a spreader or wagon.

We learned from Charles Gorbant of Jefferson County how to load marl with what is known as the "trapdoor loader." This arrangement consists of an elevated platform with an inclined plane at each end and a trapdoor in the middle through which the marl falls into the spreader beneath. In this method a slip scraper drawn by a mule or horse is used to haul the marl from the marl bed up on the platform where the scraper is dumped upon the closed trapdoor,

after which the mule passes with the scraper down the other plane and to the marl bed again, to repeat the process until enough marl is placed on the platform to fill the spreader. The trapdoor is then opened and the spreader filled. In every case where the methods described are used for loading marl, the beds are first opened up and plowed.

Until recently, practically all marl used in the state was loaded with a shovel and in most cases was dug up with hoes or picks. However, a few farmers have used manure spreaders for spreading. The fact that these laborious methods of handling marl were given by so many farmers as the reason for their not using marl led us during last July and August to go into 21 counties for the purpose of holding all-day marl plowing, loading, and spreading demonstrations. In this work, Earl G. Welch, of the Agricultural Engineering Department, and the writer cooperated with the county agents, implement dealers, and farmers in putting on the all-day demonstrations. We traveled in a Ford truck and carried with us a portable loading chute, a slip scraper, ropes, pulleys, and other necessary equipment. Local implement dealers supplied tractors, manure spreaders, and endgate spreaders. The farmers on whose places these demonstrations were held furnished plows, teams, and in many cases constructed stationary loading chutes. The New Idea Spreader Company had their state agent, Mr. Garrett, go with us after the first two demonstrations, and he carried along on a Reo truck one of their manure spreaders.

In our demonstrations we loaded marl with the portable chute, with the stationary chute, with the trapdoor loader, and with shovels. We spread marl with shovels from a wagon, with end-gate lime spreaders, and with manure spreaders of various makes.

We found the portable chute to be by far the most efficient method of loading marl. With the portable chute we loaded 2 tons of marl into a spreader in from 6 to 8 minutes. The portable chute has the advantage over the stationary chute in that it can be moved from place to place, whereas after a while, with the stationary chute, it will be necessary to drag the marl up to the chute.

We found that it would take from 15 to 18 minutes to haul the marl up on the trapdoor platform and to rake the marl into the spreader beneath. With shovels, we found that it would take two men from 18 to 20 minutes to load 2 tons of marl into a wagon or spreader.

We found the manure spreader to be the most practical means of spreading marl, from the standpoint of saving labor. In September, 1928, the New Idea Spreader Company came out with a double disk arrangement that is attached to the rear end of the spreader be-

low the apron, which spreads marl and lime a width of 20 feet. It works in much the same way as the disks of an end-gate spreader. Much interest was manifested in the various counties where demonstrations were held and we had an average attendance of 80 people per meeting.

## MARLS COMPARED WITH GROUND LIMESTONE

Mechanical analyses of a number of marl samples were compared with a mechanical analysis of a sample of ground limestone that was decidedly more finely ground than the average ground limestone now being used in the state. The marl samples were found to contain a much larger proportion of fine particles of clay and silt size and a much smaller proportion of coarser particles than the ground limestone samples. In fact, the fine material constitutes more than three-fourths and the coarse material less than one-fourth of the marl. The reverse was found to be true for the limestone, that is, the coarse material constitutes three-fourths and the fine material one-fourth of the ground limestone. This means that when equal neutralizing values of the two materials are used, marl will show up best, especially if the applications are light. In this respect marl is more like burned lime and hence is more readily available or active than ground limestone.

County agents in Kentucky, in cooperation with farmers, have conducted numerous demonstrations, using marl on sweet clover, alfalfa, the common clovers, and other legumes, as well as on corn, wheat, and other nonlegume crops. Many of these demonstrations have shown remarkable results from the use of marl. Many farmers claim that they get better results from marl than from ground limestone, which is no doubt due to the fact that marl is more readily available or active than ground limestone.

At the Princeton Substation, on soil showing a pH value of about 5.13, marl having a neutralizing value equivalent to 45% of calcium carbonate was used in comparison with ground limestone of different degrees of fineness. The amount used in all cases was the equivalent of ⅓ ton of pure limestone. Liberal applications of phosphate and potash were made uniformly on all plats. On the crop of clover thus far grown the increase in clover hay from marl was larger than that from 100-mesh limestone, or the equivalent of hydrated lime. The increase due to this small amount of marl was slightly more than 1,000 pounds per acre above the yield produced by a treatment of superphosphate and potash and was only 350 pounds short of the increase produced by 2 tons of 10-mesh limestone.

# 4. THE DEVELOPMENT OF EQUIPMENT FOR DREDGING MARL FROM THE MICHIGAN LAKES[1]

L. F. Livingston[2]

Marl has been of interest to the state of Michigan for ten years. This interest was developed in the first place by the deficiency of lime in an unbelievably large percentge of the soil in the state. There is hardly a farm in the state that does not need some lime in order to correct the acid condition of the soil. The dairy department of the College of Agriculture has been preaching and urging the need and value of feeds high in lime. Following this up, the crops department has developed a vast acreage of alfalfa in the state. Alfalfa will not grow in acid soil, and the soils department has been urging the liming of the soil to take care of the situation.

In Michigan, limestone has not been well distributed by nature. It occurs in the corners of the state, and therefore it costs the farmers, because of the freight hauls, from \$1.80 to \$5.40 per ton, f.o.b. the nearest railway station. The general price of marl is \$1.00 per yard, and experiments over a period of years have shown that 1¼ yards of 85% marl, or better, is equivalent to 1 ton of the best grade of ground limestone. Hence, the question of whether the individual should use marl or ground limestone is solvable by very simple arithmetic.

Marl is a mixture of calcium carbonate and clay, but the marls of glaciated regions, such as Michigan, are predominantly calcium carbonate. This calcium carbonate has been precipitated from ground water. The original source of the ground water is, of course, rainfall. Falling rain dissolves some carbon dioxide from the air and before it penetrates the subsoil it picks up considerable carbon dioxide from the decomposition products of the humus formed by vegetation. In uncultivated areas the concentration of dissolved carbon dioxide may be very high, due to the presence of an organic mulch on the surface.

Ground water carrying carbon dioxide in solution comes in contact with limestone pebbles in the subsoil and dissolves calcium carbonate by converting it to the soluble bicarbonate. In a short time the ground water becomes saturated. Eventually, the ground water reaches the surface either in springs or by subsurface drainage into

[1]Paper read as part of the symposium on "Lime" at the meeting of the Society held in Washington, D. C., November 22, 1928.

[2]Specialist in Agricultural Engineering, Michigan State College; now Manager, Agricultural Extension Section, E. I. du Pont de Nemours & Co., Wilmington, Del.

lakes and streams. Here the precipitation of the calcium carbonate is brought about by the loss of carbon dioxide.

In the springs the loss of carbon dioxide is brought about by a rapid rise in temperature as the water comes to the surface, very often making dry bed deposits. The marl in such deposits, because it is so rapidly formed, is often granular.

In lakes considerable marl is deposited due to the fact that the carbon dioxide is abstracted by aquatic plants, but the great bulk of deposition is due to the loss of carbon dioxide through change in temperature. The loss of the carbon dioxide converts the soluble bicarbonate to an insoluble carbonate. This change is so slow that marl from lake deposits is extremely fine, so fine in fact, that it can be used as a polishing agent for precious metals.

The farmer usually locates a marl bed by the presence of shells. There is very little real shell marl in Michigan, but almost every bed has enough shells to indicate to the farmer that marl is there, and to make him associate marl with aquatic animals rather than with chemistry.

The deposition of marl proceeds from the shoreline of the lake until there is a broad flat surrounding the lake which is underlain with marl. In many cases the lake is entirely filled in and there will remain only a swamp underlain with marl.

Some portions of Michigan are well supplied with marl, others very slightly. In 1900 a survey was made of the large deposits from the standpoint of the manufacturers of cement, but not until 1925 was anything done regarding the survey of marl beds from an agricultural standpoint. At that time Dr. C. B. Slawson of the University of Michigan was placed in charge with instructions to get information on Michigan marl deposits from an agricultural standpoint. This means the calcium carbonate content, the depth and extent of the bed, the overburden, and the accessibility. This survey has covered some 14 counties at present and will be continued until the entire state is completed.

The survey has worked out to the benefit of farmers in many cases. In Oceana County there is a fine farming group south of the town of Shelby. The land all needs lime. Some lime had been shipped in. On account of railway hauls the cost was $2.78 per ton with a 4-mile haul from the station. There were no known marl beds in the district. The survey found a bed in the center of the area from which the farmers are now getting marl for 80 cents per yard, or $1.00 for the equivalent of a ton of ground limestone with only a very short haul to their farms. In two years the survey of the whole county will be paid for by the savings in this one community.

Marl digging has been a problem in the Agricultural Engineering Department for more than 10 years. This was brought about by demand coming from farmers for ways and means of digging and using marl. Many methods were tried out. Pumping was first thought to be the best method, but later was discarded for the drag line type of machine. H. H. Musselman, head of the department, after much experimentation, designed a bucket that seemed to answer the problem so it was turned over to the extension force. The Musselman bucket is shaped very similar to any other drag line bucket. It is designed after the wood plane in such a manner that the bucket takes a shaving of marl from the bed. It operates on a slack line trolley. It has two main features. The depth gauge is a plate which hangs in front of the bucket and controls the thickness of the shaving taken by the bucket. By shortening or lengthening the chains holding the depth gauge any thickness of cut can be made. With this gauge acting as a skid in front of the bucket it is impossible to bury the bucket and get it stuck. The other main feature is a false bottom which is made of rubber belting and so arranged that when the bucket traveling on a slack line trolley reaches the point where the pile is being made, it hits a chock block which causes the belting to be brought forward and thereby makes a positive dumping device. Marl is a very sticky substance when wet and therefore until this dumping device was perfected, the unloading of marl buckets was almost impossible.

The bucket which is the most popular is one-third cubic yard in size. Almost any two-drum hoist will work this bucket, provided the hoist is strong enough to use all the power from a tractor of the Fordson type. We have used at least eight different two-drum hoists. All do the work and the speed with which the work is done is comparable to the cost of the equipment. We find that it is not economical to pull marl over 350 feet to the pile. Beyond that point too much time is lost in sending the bucket out. In most lakes and marshes all the marl that can be used is obtainable nearer the shore than 350 feet. Many ingenious farmers have varied the above equipment, but all use the depth gauge and the dumping device in some form or other.

Marl digging demonstrations were conducted very similar to any other demonstration. At the request of the county agent we visited the marl bed, picked out the sight, and arranged with the owner for poles and posts that were needed for anchorage. The demonstration was advertised the same as any other field meeting. The College received from 50 to 75 cents per yard for taking out the marl. This

money was used to help pay expenses. In many cases a meeting was arranged by the county agent some time previous to the demonstration in order to interest farmers and collect orders sufficient to warrant setting up the outfit. We have had two or three outfits digging these demonstration contracts for four years. As soon as a local man is interested to the point where he obtains an outfit, we move on to new fields. In this manner we are not competing in any way with commercial digging outfits. In 1923, about 6,000 yards of marl were used. In 1927, almost 500,000 yards were used. We estimate that every yard of marl used saved the buyer $1.00 over the cost of an equivalent amount of ground limestone.

The only feature of marl digging that differs materially from any other drag line operation is the removal of muck or other overburden material. This has been done very quickly and economically with dynamite. The dynamite used is a 50% straight nitroglycerin variety which is ordinarily used for ditching operations. Usually, a single row of holes 18 inches apart with two sticks in each hole is sufficient to remove all the muck for the digging of one or two trenches. In other words a ditch about 10 feet wide is made and the material is removed and put all over the surrounding landscape.

Ninety per cent of the marl used in Michigan is spread with the manure spreader. We used to think that the only way to do a good job was to haul the marl to the edge of the field and pile it in small piles to allow it to dry out thoroughly, but from experience we find that marl can be handled with almost any amount of moisture in it. One of the most interesting examples is on the Kellogg farm near Augusta. A small lake lies in the center of the farm, and 1,500 yards of marl were taken out last fall. It was decided to try to get the marl on the land during the winter. As soon as it froze work was started. The spreader with team and man was left in the field. The marl was brought by one team, two men, and three wagons, one at the bed, one at the field, and one on its way between. In this manner as many as 61 yards have been put on in a single day at the rate of about 5 yards to the acre. The marl pile froze about 6 inches deep. The loading entrance was kept open by covering at night with straw. This system, we believe, will be used by many farmers in Michigan this winter.

Any type of manure spreader may be used. In the types that do not have a movable bottom, however, it is advisable to put in a small amount of straw or other similar material in the bottom of the spreader before loading the marl. The main point is to have the marl come back in such a manner that the beaters will catch it readily.

Some marl has been so well dried that it is put through a lime drill, but this is an exception rather than a common practice. Frank Chenery of Kalamzoo, who is one of Michigan's oldest marl users, has developed a spreading system that is worthy of note. Mr. Chenery hauls his marl in the winter when not otherwise busy and piles it in bushel size piles over the field. In the spring these small piles, being above the ground, thaw more quickly than the soil itself, hence they can be handled before the soil is ready for plowing or cultivation. Mr. Chenery uses a six-tined fork with a piece of galvanized sheet metal wired to the face of it in such a manner that the fork is turned into a shovel with 1½ inches of the points sticking out below the blade of the shovel. He claims that walking through the field with this tool he can spread these small piles as easily as he can load the marl into a spreader and get the job all done before time for spring plowing. Quite a few farmers are following his lead.

We have done considerable work on an end-gate spreader for marl, but up to the present time feel that it is too complicated.

# SYMPOSIUM ON "SOIL EROSION"

*Leader*: H. H. Bennett, U. S. Dept. of Agriculture.

1. Erosion in the Orient as Related to Soil Conservation in America. W. C. Lowdermilk, U. S. Forest Service.
2. The Results and Significance of the Spur (Texas) Run-off and Erosion Experiments. R. E. Dickson, Texas Agricultural Experiment Station.
3. Erosion on Range Land. W. R. Chapline, U. S. Forest Service.
4. The Prevention of the Erosion of Farm Lands by Terracing. C. E. Ramser, U. S. Dept., of Agriculture
5. The Necessity for Soil Conservation. A. K. Short, Federal Land Bank, Houston, Texas.

## 1. EROSION IN THE ORIENT AS RELATED TO SOIL CONSERVATION IN AMERICA[1]

W. C. Lowdermilk[2]

Every act of cultivating the soil without certain precautions may be considered to accelerate the normal geologic processes of denudation and erosion which were in operation previous to agricultural occupation of the land. We are concerned here with a consideration of the erosional processes which human occupation in China, particularly, and in Korea has accelerated beyond the geologic norms for the regions considered. We here contemplate the process of accelerated erosion which, in the United States, as well as in China, reduces the aggregate productivity of land areas supporting human occupants. We have at present no measure of the magnitude of the reduced productivity, yet there are unmistakable indications of a gradual reduction in the course of time of the "carrying capacity" of the land for man, or if not that, a lamentable lowering of his standard of living.

Erosion and denudation are differentiated by Penck (10)[3] and others. "Denudation" is employed as a term to designate the slow down wearing of the country rock through weathering, soil creep, and other processes. "Erosion" is employed to designate the abrading and corrasive action of currents of wind, ice, and water. Since this discussion is restricted chiefly to the loss of soil occasioned by flowing

[1]Paper read as part of the symposium on "Soil Erosion" at the meeting of the Society held in Washington, D. C., November 23, 1928.

[2]U. S. Forest Service, Washington, D. C.

[3]Reference by number is to "Literature Cited," p. 414.

water, erosion caused by wind, while important in some regions, will receive only secondary consideration; and erosion by ice none at all.

Above the oceanic tidal zone the processes of denudation and erosion alternate with those of aggradation and alluviation. The rate and intensity of erosional processes are dependent upon a number of factors, chief of which are gradient differentials responsive to tectonic movements, soil development, vegetation, and climate. Under climate is considered temperature amplitudes, especially above and below freezing, and their means; precipitation, its character as rain or snow, its distribution, intensities and amount; and the evaporation factor of the atmosphere. In a more exact sense both soil and vegetation become in the process of time reflections of climate when not affected by human occupation or man's agencies. Erosional norms are responsive to and become processes nicely adjusted to and conditioned by geologic structures and formations and by different climatic types. The Köppen (6) classification of the climates of the earth furnishes a logical basis for the determination of erosional norms.

Erosional processes in arid regions have received most attention because of their conspicuous features. It is, however, in the humid, semi-humid, and semi-arid regions which support the great majority of mankind that erosional processes require the most exact measurement and study.

As man has advanced in his powers over nature and has brought to his assistance improved tools and machines, he has become more and more effective in removing the natural mantle of vegetation and in exposing the soil to the operation of the forces of wind, flowing water, and gravity. Fire, intentionally or accidentally set, man's herds, and finally his plow, all have contrived to accelerate the processes of denudation and erosion. It is only by constructive and conservative management of soil resources that these headlong processes of erosion may be arrested or reduced to their norms.

The Orient, as the dwelling place of agricultural man for several millennia, furnishes an attractive field of study of accelerated erosional processes, their direction, and magnitude after centuries of operation. The writer's studies (7, 9) reported in part elsewhere have only touched on the significance of the problems involved. It is the purpose of this paper to indicate some general conclusions which must be considered as tentative, and to call attention to the need of more detailed studies of these processes in the Orient to contribute to the evaluation of the processes now in their early stages in this country, and finally, to their control.

Such works as that of Bennett and Chapline (1) and Bennett (2) have set forth in a convincing manner the gravity of the erosion problem in the United States. An urgent need exists for the isolation and quantitative measurement of accelerated erosion, to make known not only its magnitude but its rate of acceleration and its trend as a basis of support for and means of its control.

Erosional history in the Orient furnishes, therefore, an important background in the examination of the problems confronting us in this comparatively recent and rapidly exploited land surface of the United States. The writer's first-hand knowledge of conditions in the Orient is confined to portions of China, Korea, and Japan. India doubtless would serve as an example in much the same way.

Erosion in China must be considered in relation to climatic types and physiographic formations. For this purpose China proper is divided into three broad regions as follows: (a) South China, including the drainage basins of the West and Min Rivers; (b) Central China, including the drainage basin of the mighty Yangste River; and (c) North China, including the drainage basins of the Hwai and Yellow Rivers, and of the combined delta plains of these two rivers.

South China is characterized by mountainous topography with delta plains on the seaboard, drenched by a heavy monsoonal rainfall of 60 to 80 inches or more which falls principally in the spring and summer months. The winters are dry (4). Köppen's climatic formula for the region is *Cw*—mesothermal with dry winters. The summer temperatures, however, are semi-tropical and combined with abundant moisture in the growing season favor rank growth of natural vegetation. Such conditions also favor the quick return of vegetation on any exposed or abandoned cultivated lands.

Except for the alluvial soils in deltas and narrow river valleys, the soils of the sloping lands are residual. The culture of rice which requires terracing is followed on the valleys and lower slope lands. The demands for food and textiles have required the cultivation of slopes, which has brought about erosion during cultivation. The rapid return of natural vegetation serves as an effective check on excessive erosion as soon as cultivation is stopped. David (3), the Jesuit naturalist, described serious effects of slope cultivation in the Province of Kwangsi as well as in the Province of Yunnan. Accelerated erosion is not as serious a problem in South China as in Central or North China.

Central China is characterized also by mountainous topography, except for the delta of the Yangste River and alluvial plains in the

Provinces of Hupeh, Kiangsi, and Yunnan, and the red soils of the Szechuen plain. The precipitation occurs chiefly as rain in the summer months and averages over the Yangste basin approximately 40 inches per annum (4). The winters are dry. The temperature amplitudes are greater and the effects of the dry winter winds out of Central Asia are more pronounced than in South China. Cold dust storms reach as far south as the Yangste River one or more times each winter. The Köppen climatic formula remains *Cw*, nevertheless. Except for the alluvial delta and river plains and a narrow strip of heavy-textured loessal soils south of the Yangste River, the soils of this region are residual. Natural vegetation is less rank than that of South China, and originally consisted chiefly of deciduous hardwood forests.

Rice culture is followed wherever irrigation water is available, and requires terracing. Terracing is intensively developed on very valuable land near large cities. Slope cultivation without terracing is common in interior places and has accelerated erosion to a marked degree in some parts of the Yangste basin. The return of vegetation following abandoned cultivation is rapid enough to stop serious erosion. Grazing of sheep and goats is uncommon in Central China as well as in South China, and little grazing of cattle takes place. Grasses however, are annually harvested chiefly for fuel for which stoves are especially designed. The problems of erosion may be considered intermediate generally but serious in localities.

North China is characterized by the great combined delta plain of the Hwai and Yellow Rivers and by a mountainous hinterland covered in large part with the great loess deposits of Northwest China (10). Two narrow alluvial plains within the hinterland are important, elsewhere the exposed soils are residual. The precipitation of the Yellow River basin varies from 40 inches in the south to less than 10 inches on the border of the Gobi Desert, and averages less than 20 inches per annum. It occurs chiefly as torrential rain in the summer months (4). The winters are cold and dry except that a thin mantle of snow falls in the mountains. This snow on melting in the spring is important in supplying vegetation with moisture at the beginning of the growing season. The northwestern part of this region falls under the *Dwa* Köppen formula, meaning microthermal, dry winters with mean temperature of the warmest month above 22°C (71.6°F). The southeastern part of the region falls within the general *Cw* type of Central and South China.

The primeval vegetation consisted of coniferous forests on the mountains above contours lying between 4,000 and 5,000 feet above

sea level, according to location in the region. Shrub and xerophytic vegetation occupied the lower slopes and benches, whereas deciduous woodlands and forests occupied the subirrigated alluvial valleys. The return of natural vegetation on abandoned land varies with altitude and is generally slow because of the paucity of moisture and severity of long dry winters and short growing seasons.

Despite the great area of delta lands and comparatively restricted alluvial river plains, the resident population many centuries ago exceeded, under the prevalent methods of agriculture, the carrying capacity of the plains. This carrying capacity has reached a figure of more than 1,000 persons per square mile over extensive regions, with however a corresponding lamentably low standard of living. Slope cultivation followed of necessity to supplement the production of the plains. As residual soils were washed away and loessal soils were cut up by gullies, cultivated lands were progressively abandoned. The general grazing of sheep and goats on mountains and abandoned fields, as well as the general raking of the ground everywhere in the autumn for all the leaves and loose grass for fuel, are factors which serve to retard the return of natural vegetation on uncultivated areas.

Erosional processes under these conditions have developed to great proportions corresponding to the origin of the soils. Residual soils are removed from cleared slopes by sheet erosion and by gullies whose depths are limited by coarse partially weathered fragments of the country rock. Erosion is automatically checked in these instances by the accumulation of residual rock fragments, which may be termed "erosion pavement."[4] The deep deposits of loess are eroded by enormous labyrinths of gullies whose vertical walls on being undermined by torrential summer flood flows break into great blocks, cave into the raging stream, and rapidly melt away to furnish the run-off waters with heavy burdens of silt. The summer drainage streams cut downward into the loess to great depths determined only by the level of the main drainage valley. The return of natural vegetation has not been able to keep pace with these accelerated erosional processes. They appear to have increased in geometric ratio until they have developed to phenomenal proportions over extensive areas. It is a notable fact that the region of China enjoying the least rainfall suffers most from erosion and from flood damage.

It becomes a difficult task to differentiate between the geologic norm of erosion for this region under semi-humid to semi-arid conditions and the accelerated erosion beyond this norm. The great delta of the Yellow River is evidence enough of the magnitude of

[4]A term suggested by C. F. Shaw.

the processes normal to this region since Tertiary times. Climatic fluctuations in the past are reflected in the present day cutting by streams into former valley fills. Willis, et al (11) concluded that accelerated erosion exists. One of the most conclusive evidences of accelerated erosion, however, is found in the Buddhist temple forests and groves (6).

Under Imperial favor in the first century, A.D., during the Hahn Dynasty, Buddhism spread rapidly in China. Temples were established throughout the country, particularly in the mountains, until each village has its temple. Forests and groves of trees were retained or established with native species about the larger temples, and have generally been effectively maintained for nearly 20 centuries to the present time. In fact, much of the revenue of the temples is derived from the products of the temple forests according to sound methods of forest management. In the studies of temple forests by the writer, the first fact to be determined by examination was whether the vegetation of the temple forests was reproducing naturally, i.e., without artificial help as by sowing, planting, or irrigation. Wherever natural renewal of vegetation was found to exist, as was generally the case, it was assumed that similar sites in the region would support a similar vegetation cover. Quantitative studies (8) to compare the influence of temple forest vegetation on surficial run-off of rain with that of abandoned fields were made in the Provinces of Shansi and Shantung during the rainy seasons of 1924, 1925, and 1926, whereby the influence of natural vegetation on run-off was measured quantitatively.

It appears possible to conclude on the basis of the temple forests that if all human occupants were removed from this region of North China, a mantle of vegetation of varying density and composition would within a varying number of decades cover the entire land surface, and would very possibly reduce to an important but unknown extent the present rate of erosion.

These studies indicate that erosion has been accelerated generally in North China beyond the norm that would characterize the region uninhabited by agricultural man. Agricultural cultivation of sloping lands has been chiefly responsible for this accelerated erosion. Huc (5), a Jesuit explorer, during his memorable expedition to Lhassa and return in 1844–46, came to a similar conclusion.

While soils have been removed from the uplands, they have accumulated in the drainage streams and their valleys as sorted cobble, gravel, sands, and silts of which the finer fractions have been carried to the sea in torrential run-off waters. Silt contents up to 21.9% by weight were measured by the writer.

Flood phenomena are associated in a marked degree with excessive silting of the diked stream channels, in response, it is believed, to this accelerated erosion from the uplands.

Efforts to reclaim eroded land or to reduce this erosion are found in terracing which, unfortunately, is confined to an altogether inadequate portion of the region of both Central and North China. Terracing is employed about cities in North China and where land values are high. A type of terracing loess slopes is produced by the method of plowing. Slopes are divided into narrow contour fields. A type of plow is used which can be made to throw the soil either to the right or left by inclining the handle. Annual plowing cuts down the upper edge of the field and builds up the lower. A strip of natural vegetation may be left on the field margins to protect the edge of the terrace that gradually develops.

Wherever in China terracing is employed the danger of excessive erosion is removed. Level lands of the plains and of the terraces are saved for continuous cultivation. Terracing, however, is restricted by the availability of irrigation water for rice culture, and by land values. Assuming that the present methods of clearing and cultivaing slopes were employed as cultivation spread over the country from early times, it is probable that terracing has been employed principally as a means of reclaiming cultivated and eroded land, except in the case of rice culture. Consequently, only land of high values can be thus reclaimed.

There is left an extensive area of hill and mountainous lands, particularly in Central and North China, whose value will not justify the labor of terracing. This extensive area falls into two climatic subtypes. In one the climatic conditions are such that natural vegetation returns promptly on abandoned slope fields. The process of "shifting cultivation" very much as is reported from mountainous parts of India (12) is employed. After a number of years, varying from 20 to 50 and more, the natural mantle of vegetation builds up a fertile vegetable soil. The farmer, usually a tenant or small owner, clears the land and grows his crops of wheat, maize, flax, oats, potatoes, or millet as long as the harvests pay him for his seed and labor. This period varies from 3 to 15 years, conditioned chiefly by the gradient of the slope and the consequent rapidity of the erosion of the surface soil. It does not pay to fertilize sloping lands. Thereupon the transient farmer moves on and clears another field until cultivation has been pushed to the tops of the highest mountains, 8,000 feet, in Shansi, Shensi, and Shantung. The cultivation line rises and falls in response to population pressure in the valleys. Famines have tended to lower the cultivation line (7).

In the other subtype the climatic conditions are such that natural vegetation returns very slowly on abandoned lands. Where grazing of sheep and goats is practiced, great areas are prevented from recovering and erosion goes on apace, increasing in geometric ratio. Such regions present the appearance of badland, whereas temple forests within many of such phases of erosion justify the belief that the erosion is in excess of the geologic norm for the region. Extensive areas in the Provinces of Shantung, Shansi, and Shensi fall into this subtype.

The total absence of community, provincial, or national action in the past to remedy the evil of erosion throughout China has left the small land owner and tenant helpless for lack of resources. The principle of equal inheritance has tended to keep land divided into small ownerships. Two conspicuous aspects of the situation deserve especial attention. They are (a) the traditional policy of the government of China in the past of non-direction or *laissez faire* in matters of soil, forest, and water conservation; and (b) the plight of the small owner in the presence of processes of erosion with which he has been unable to cope single handed once they have been permitted to get underway.

The damages of erosion are not restricted to the eroded areas; they extend to the lands in the valleys in the form of covering fertile fields with coarse material, in silting stream channels, and in the interference with the regime of waters whereby storage of water for power and irrigation are practically impossible. The Chinese slope farmer beyond the terraced lands unwittingly sets in motion processes of erosion before which he stands helpless; and likewise the farmer of the valley stands helpless before the outwash of debris upon his small holdings. The conclusion seems inescapable that this manner of treatment of soil resources has gradually reduced the aggregate productivity of the land area, and that it has taken place in the face of an increasing population.

Another picture in the treatment of soil resources is presented in the Japanese Empire and particularly in Japan proper. From ancient times the Japanese nobles of ruling dynasties maintained an effective control of wooded lands in the mountains. In the past half century the modern Japanese Government has put into operation a directive policy in the treatment of soil, forest, and water resources. The writer has indicated elsewhere (8) some of the specific restrictions and work of erosion control which has reached a stage of development in Japan unexcelled in any other country.

Steep young topography supplied with heavy rainfall of torrential character to depths of from 40 to 60 inches per annum has, on the one hand, made the policy of the Government necessary, and, on the other, has contributed to the success of erosion control. The precipitous nature of the topography and the wide extent of light and loose volcanic ash soils have presented difficulties in erosion control whose conquest commands highest praise.

So abrupt are the mountain slopes, so narrow the alluvial valleys, and so valuable is the valley land for rice production that any erosion on slopes the debris from which would cover the rich rice paddies becomes a serious menace to sustained food production. The seriousness of this menace is reflected in the large expenditures for erosion control. On the basis of works by the Department of Agriculture sums up to 10 times the value of eroding land have been required in controlling erosion after it got under way. Such expenditures are not justified on the basis of land reclaimed nor to a small private owner of land. It can only be justified as a community or national measure to maintain the aggregate productivity of the country's soil resources. The expenditures are obviously made to prevent the destruction of valuable valley lands and to stop a menace which if unchecked would grow in geometric ratios. Such high costs in erosion control demand the greater vigilance to prevent the inception of excessive erosion.

The measures employed in erosion control in Japan may be briefly summarized here. Two principles guide in this work. They are, first, the establishment of a base level of erosion for the drainage channel. Check dams and such works are employed for this purpose. These stop the downward cutting of the stream, a condition which permits the eroding slopes to come to an angle of repose. Retaining walls may be employed to prevent undercutting by a meandering stream. Several years are often allowed for the eroding slopes to reach such an angle of repose. Natural vegetation frequently reclothes these slopes without artificial aid. The second principle is artificial revegetation of the eroding surfaces, where the angle of repose is not rapidly reached, or when for one reason or another such measures are considered necessary. In many instances it may be necessary to cut down gully walls to a given gradient and to terrace the land preparatory to its revegetation to shrubs and hardy trees. The accomplishments of this nature in Japan deserve a thorough study.

Whereas in Japan the works of erosion control have been chiefly those of repairing breaks in the mantle of vegetation which generally clothes the mountain slopes, the problem in Korea (Chosen) is one of

applying control measures to an extensive landscape where unrestricted use and abuse from ancient times, as in China, have produced erosional damage of great proportions. So damaged are the alluvial valleys that the justifiable costs of erosion control is far below that of Japan proper. Furthermore, the work required is of such extent that financing of intensive erosion control exceeds practical possibilities in the present decade.

A new attack has been made by the Chosen Forest Experiment Station located at Seoul. The minimum of masonry work is employed. On the other hand, reliance is placed on the use of hardy vegetation and check dams of grass turf which are located where drainage channels are small. Effort is made to create check dams of living and growing vegetation. On the faces of slopes seed of leguminous plants, such as *Lespediza bicolor* and *Amorpha* sp., are sown in contour furrows. Soil inoculated with nitrifying bacteria is mixed with the seed before sowing. Promising results have been achieved, and these experiments deserve to be followed with keen interest by all who are concerned with erosion control.

While many of the factors surrounding erosion in the Orient find no counterpart in the problems of erosion in America, yet it seems worth while to recapitulate certain features in the light of American problems. Climatic conditions are only partially repeated in the two continents. Loessal soils occur in both regions and exhibit similar manners of erosion. The cultivation of the soil in America has been in operation for a very short time comparatively. It has not been as intensive but with such disregard for soil conservation that already serious losses have been suffered by the nation. The chief problem in America is to prevent excessive erosion of soils; in China it is rather to reclaim badly eroded soils.

The experience of the Orient indicates four points worthy of consideration in our problems in America. They are:

1. Erosion when uncontrolled reaches a stage, often rapidly, particularly on sloping lands, where the value of the land will not justify the expenditure necessary for erosion control thereon. The individual owner of such land is left without recourse when excessive erosion gets underway; he stands helpless before his loss. Likewise the individual owner of damaged lands in the valley stands helpless before his losses.

2. The community interest in the erosion problem must be awakened to prevent the spread of erosional processes.

3. The control of erosion is justified very much as the suppression of a forest fire. It pays the community to stop a menace which grows in geometric ratios.

4. It is most important of all to learn from the experience of the Orient that accelerated erosional processes are like a malignant disease, and that it is imperative that erosional processes should be held to their geologic norms by constructive soil management to save enormous losses in land values and production, and costs of erosion control works.

## SUMMARY

Central and North China are believed to furnish examples where agricultural occupation of the land has throughout several millennia accelerated erosion of soils beyond that which existed previous to soil cultivation in these regions. The temple forests of China furnish criteria of comparisons and suggest this hypothesis. China represents the logical outworking of a traditional government policy of non-regulation or non-restriction in the use of soil resources. Japan represents the operation of a directive policy in the use of soil wherein erosion control has been effected at costs in excess of the value of the eroding land for the purpose of preserving food-producing lands in the low-lands. Excessive erosional processes when left to proceed unchecked under certain climatic types destroy land values beyond the costs of reclamation. Accelerated erosion becomes a community and national menace and for that reason requires laws for its treatment if the latter is unobtainable by education and demonstration.

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# 2. THE RESULTS AND SIGNIFICANCE OF THE SPUR (TEXAS) RUN-OFF AND EROSION EXPERIMENTS[1]

R. E. DICKSON[2]

In nearly every section, water or soil fertility, or both, are limiting factors in crop production. Until quite recently the losses in soil fertility were accredited chiefly to poor judgment on the part of the farmer in the selection of the cropping system on his land. But it is being recognized more and more that the losses of soil fertility taking place through erosion are many times greater than the losses by even the poorest cropping system. With the realization of this fact we can consider soil fertility losses by erosion and water losses as concomitant, as water is merely the vehicle by which soil fertility is transported from the land. Since we know that by certain methods conservation can be practiced by the land-owner, a great field lies before us in developing information as to the extent to which these losses occur on our farming, grazing, and forest lands, together with studies to determine the most effective means of checking these losses.

The characteristic downpours of rain, so common in the West, contribute heavily to this wastage of water and soil, which seems to be avoidable in a large measure if suitable methods are developed to hold the water on the land until it has had time to penetrate.

This wastage of both water and soil fertility becomes a matter of urgent importance to the whole western half of the United States as this region generally produces its crops under limited water conditions and is rapidly becoming depleted of its soil fertility which has probably played an important rôle in the production of grains and other products rich in protein. Already the wheat growers realize that with the declining supply of nitrogen in the soil there is a reduction in the protein content of wheat. The same might be said for cotton, although the development of cotton farming in the western part of the region has been carried on hardly long enough to show noticeable effects.

## RESEARCH NEEDED

Very little is known about the nature of the rainfall. We have records, it is true, and know with a fair degree of accuracy the average annual rainfall for any given region. We have measures of the monthly rainfall and even the daily rainfall, but we have failed in

[1]Paper read as part of the symposium on "Soil Erosion" at the meeting of the Society held in Washington, D. C., November 23, 1928.

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general to take into account the duration of the rainfall in any given day, and, therefore, know very little about the intensity of the rainfall other than from such observations as have been made from time to time by laymen. We know very little about the reaction of the principal soils of the United States to erosion. We know very little about the relationship of the slope of the land to run-off water on different soil types. A limited amount of data are available as to the effect of different crops on preventing water and soil losses. A considerable amount of work has been done as to the effectiveness of tillage in storing and holding water on the soil, but not enough has been done as to the relation of tillage to infiltration. We know little about the type of terrace and other obstructions which are most effective in preventing water run-off and soil erosion. It has a direct bearing on the whole water and soil conservation problem as a means of keeping out of the streams much of the present surplus flow which is lost to the areas that need it most, and which carries immense quantities of soil and plant food to the sea, thus depleting soil fertility on the uplands and causing disaster to overflow sections along the principal streams. Altogether the field is rich in possibilities for the research worker in determining the factors responsible for such waste and in evaluating the most effective methods of prevention.

## TEXAS RUN-OFF WATER AND SOIL EROSION EXPERIMENTS

In 1926, experiments were inaugurated at the Spur Experiment Station, located in northwest Texas in the section known as the rolling plains region and where originates the net-work of many small streams which finally converge forming the Brazos River.

The average annual rainfall at Spur is 21.68 inches. The altitude is 2,274 feet. The soil on which these particular experiments are placed is classified as Miles clay loam.

### PLAN OF EXPERIMENT

The project embraces a series of eight small control plats, 1/75 acre in size, being 6 feet wide and 96.8 feet long. They are bordered with heavy galvanized iron having calibrated concrete tanks at the lower ends with sufficient capacity to hold the water lost and the soil eroded during the heaviest rain periods. These control plats are similar to the ones in use in erosion and run-off experiments at the Missouri and North Carolina experiment stations.

In addition to the control plats in the layout of this experiment there are 10 field areas, each of them being approximately 10 acres in size. At the lower corner of six of these areas is a concrete weir and an automatic water stage recorder which furnishes a definite measure

of the amount of water that passes from the area. Two other field areas are terraced so as to hold all of the water that falls on them, and the remaining two hold all of the water that falls on the land and an additional measured amount that comes as run-off losses from other areas.

## DISTRIBUTION OF RAINFALL

Of the 21-inch annual rainfall 84% comes during the growing period of summer crops and is fairly well distributed through the months of April to October, inclusive, with the exception of a period in mid-summer, centering in July, that is normally low. During the 17 years over which records are available, there have been 9 years when there was less than an inch of rainfall in July. The presentation of the rainfall over 17 years locates rather definitely two distinct rain peaks in the spring, a dry mid-summer starting in June and lasting well into August, followed with more favorable conditions the latter part of August and September. This dry period is not a local condition but prevails throughout the Great Plains section of the United States and well toward the east into cotton and corn belt states. Favorable rainfall the latter part of August and September is responsible in a large measure for the rapid development of the southern Great Plains region and the western extension of the cotton belt.

In view of the seasonal distribution of rain it is obvious that as much as possible of the water from the spring rains should be stored in the soil for the use of growing crops in the summer. All too frequently crops are brought to the heavy fruiting stage and enter a period of depressed rainfall without sufficient moisture to mature a full crop.

A knowledge of the seasonal distribution of rainfall also furnishes a splendid index for planting dates in order to bring the crop into maturity under more favorable conditions. Over a large portion of the cotton belt every possible means is used to mature the crop as early as possible in order to evade the ravages of the cotton boll weevil that usually appears in destructive numbers in late summer. In the western border of the cotton belt there are no boll weevils and cotton is planted late so that it will come into fruiting under the more favorable moisture conditions that prevail during August and September. By a rigid conservation of water from the spring rains the crop is safely carried over the dry midsummer and is brought into this favorable fruiting period in a healthy, vigorous condition. This is essential not only with the cotton crop, but with the grain sorghums and other row crops as well.

The data given in Tables 1 and 2 cover the period from June 18, 1926, to October 15, 1928, or the major portion of three crop years, and represent average conditions fairly well. The precipitation in 1926 was the heaviest since the station was established in 1911. The years 1927 and 1928 were dry, with the average for the three years being an inch less than the normal rainfall.

TABLE 1.—*Acre inches of run-off water loss from control plats.*

| Year | Rainfall, inches: Total | Rainfall, inches: Ineffective showers | Run-off water in inches with per cent slope of land, crop, and treatment: 0% Cotton | 1% Cotton | 2% Cotton | 2% Fallow cultivated |
|---|---|---|---|---|---|---|
| 1926 | 27.99 | 2.50 | 1.03 | 6.91 | 7.13 | 12.33 |
| 1927 | 16.12 | 6.59 | 0.21 | 0.37 | 0.57 | 1.82 |
| 1928 | 16.79 | 4.39 | 0.63 | 3.00 | 3.70 | 4.71 |
| Total | 60.90 | 13.48 | 1.87 | 10.28 | 11.40 | 18.86 |
| Average | 20.30 | 4.49 | 0.62 | 3.42 | 3.80 | 6.28 |
| | | | 2% Fallow, not cultivated | 2% Buffalo grass | 2% Milo | 3% Cotton |
| 1926 | 27.99 | 2.50 | 12.09 | 4.46 | 5.62 | 5.68 |
| 1927 | 16.12 | 6.59 | 3.51 | 0.00 | 0.17 | 0.55 |
| 1928 | 16.79 | 4.39 | 7.58 | 0.11 | 0.87 | 3.24 |
| Total | 60.90 | 13.48 | 23.18 | 4.57 | 6.66 | 9.47 |
| Average | 20.30 | 4.49 | 7.72 | 1.52 | 2.22 | 3.15 |

TABLE 2.—*Soil losses from control plats in tons per acre.*

| | Loss in tons per acre with per cent slope of land, crop, and treatment | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Year | 0% Cotton | 1% Cotton | 2% Cotton | 2% Fallow cultivated | 2% Fallow not cultivated | 2% Buffalo grass | 2% Milo | 3% Cotton |
| 1926 | 14.21 | 20.65 | 27.71 | 40.71 | 38.65 | 11.32 | 15.86 | 28.67 |
| 1927 | 0.88 | 1.61 | 1.59 | 3.46 | 6.83 | 0.00 | 0.44 | 2.28 |
| 1928 | 0.77 | 5.66 | 8.55 | 11.71 | 19.82 | 0.08 | 0.93 | 7.39 |
| Total | 15.86 | 27.92 | 37.85 | 55.88 | 65.30 | 11.40 | 17.23 | 38.35 |
| Ave. | 5.28 | 9.30 | 12.61 | 18.62 | 21.76 | 3.80 | 5.74 | 12.78 |

## CHARACTER OF THE RAINFALL

A knowledge of the character of the rainfall in any region is of importance in an effort to minimize water and soil losses. At Spur for the past three years the rainfall has been measured by the use of self-recording rain gages, giving a 10-minute reading on the fall. Hence, information is available as to the intensity of the rainfall. In the study of these records it is evident that approximately 25% of the total annual rainfall in this region occurs in isolated showers

amounting to less than 0.5 inch and can be classified, therefore, as ineffective rainfall. Approximately another 25% is lost by run-off, leaving about 50% of the annual total, or 11 inches, of effective rainfall on which to grow the crop.

Since there is no means of eliminating the loss of rainfall sustained through ineffective showers, the whole water and soil conservation problem is primarily concerned, therefore, with the control of water from torrential rains.

### EFFECT OF SLOPE OF LAND ON LOSSES

As shown in Tables 1 and 2, there are four plats planted to cotton having gradients of 0, 1, 2, and 3%. There is undoubtedly a discrepancy in the last plat due to a large dirt fill at the upper end of the plat in establishing the grade. It will be noted that in each of the three years the level plat had comparatively small water losses or about one-fifth as much as the plat with a 1% grade. The same relative difference does not exist between the plats with a 1% and 2% grade, the difference in the water losses being small and fairly consistent through the three years. This indicates rather clearly that it does not require much of a slope for water to flow off the land. Probably the greatest beneficial results can be secured by water conservation practices and at a minimum cost on comparatively level land. This is emphasized more forcefully in the data from the field areas to be discussed later in this paper.

### EFFECT OF CROPS ON LOSSES

Control plats with a 2% grade are planted to cotton, milo, and buffalo grass; another is fallowed and cultivated; and one is fallowed and not cultivated, except that the weeds are clipped with a hoe. From the results of this series of plats is derived a clear indication of the tremendous water and soil wastage resulting from cropping practices on farm lands and from the over-pasturing of domestic animals on grazing lands. These results also show a cause of the waning productivity in the cotton belt and possibly a new viewpoint for observing crop rotation studies.

As previously mentioned, these plats were set in operation in June, 1926. The grass plat was sodded on June 15 and a solid turf was not obtained until late in the fall. Practically all of the 4.46 inches of water lost from this plat was before the sod had formed inasmuch as it occurred during the time of the torrential rains in July and August when the rains totaled 14.41 inches. In 1926 there was no vegetative litter on the plats as a residue from the previous year's crop. The cotton and grain sorghum plants were left on their

respective plats at the end of the 1926 and 1927 crop season. The milo plants furnished a much larger vegetative litter than did the cotton plants and consequently a greater obstruction to water movement. Buffalo grass has been the most effective crop in preventing water losses and since becoming fully sodded has been practically perfect in preventing run-off. Similar results have been obtained at the Missouri and North Carolina stations. There is little cause to question the fact that the water losses from grazing land has been materially increased by over-pasturing and that this practice has resulted in the destruction of this natural obstruction to water movement. There is also much evidence that the milo plant, acting as a cover crop while growing and later furnishing a large plant litter, is far superior to cotton in preventing run-off water losses.

## TILLAGE AS AFFECTING WATER LOSSES

Tillage plays an important part in preventing water losses. A fallow plat spaded to a depth of 4 inches in the winter lost a little more than one-half as much water in 1927 and 1928 as a fallow plat not spaded or cultivated but which had the weeds removed with a hoe. It appears from the measurements of losses occurring, and also from other observations made during the three years, that cultural methods can be improved in handling row crops so as to maintain the surface soil in a better condition to prevent run-off water losses. A great deal of emphasis in the past has been placed upon locking the water up in the soil through the maintenance of a dust mulch and through frequent cultivations. Recent experiments on the effects of cultivation show conclusively that the greatest beneficial result is the destruction of weeds whose growth makes heavy drafts on the moisture and available plant food supply. It thus appears that tillage studies having for their objective the prevention of water losses are needed. In other words, tillage studies should deal with the storage of water in the soil as well as with its retention in the soil. A clod mulch should probably replace the dust mulch.

## SOIL LOSSES FROM CONTROL PLATS

In the beginning of these studies very little importance was placed on erosion of the soil. After the first rain period, however, such an enormous amount of soil and organic matter was found in the pits that it became evident that the plats were vulnerable to considerable soil-wash, and that the wastage of the soil due to sheet erosion would in a comparatively short time impoverish the soil and make it impenetrable and intractable through the loss of the upper soil rich in absorptive organic matter.

The soil losses from the control plats are highly correlated with the water losses. Soil eroded and carried to the pits with each 1,000 gallons of water has been approximately the same for the various plats. It appears that water and soil losses are concomitant and that any practice that accentuates water movement from the land at the same time creates an accelerated soil movement in the same direction.

A large portion of the soil losses from erosion occurred with torrential spring rains at a time when there was no crop covering to check the erosive action of the run-off water. These same dashing rains which carry off the richest of the surface soil in their unrestrained overland rush to the sea are the ones that should be conserved for the plant's use in mid-summer.

John J. Ingalls in his splendid tribute to grass says, "Its tenacious fibers hold the earth in its place, and prevent its soluble components from washing into the sea." Since the grassed plat has become thoroughly sodded, it has proved to be a most efficient soil-conserving mat and represents a fairly perfect sample of nature's method of soil building. Next to grass, milo has been the most efficient crop in the prevention of soil wastage by erosion. The soil losses from the milo plat with a 2% gradient have not been as heavy during the past two years as the soil losses from the level plat planted to cotton. It is highly probable that the crop rotation studies reported throughout the country have not given proper credit to the plant and plant litter in retarding run-off water losses and preventing soil fertility losses through erosion.

The greatest soil losses are from the fallowed plats with an average annual acre loss of over 21 tons of soil from the fallowed plat with a 2% gradient and not cultivated. It is also interesting to note, in comparing the water and soil losses, that from six of the plats practically 3 tons of soil eroded per acre with each acre-inch of water lost.

### THE FIELD AREAS

Two field areas were surveyed and terraces constructed in the spring of 1926, but as recorders were not available at that time a measurement of water losses was not secured. The remaining eight plats were laid out and the recorders and weirs installed in 1927. These field areas have furnished some remarkably valuable information which is now being used as a basis for the construction of terraces on farm lands in Texas.

On land with a natural slope of 1%, which is considered practically level in many parts of the country, an increased yield of 42% in a cotton crop was made from level terraced areas in 1926 over land that was not terraced.

Two field areas were terraced with a vertical fall of 2 feet between terraces. On one area the terraces were built with the contour of the land and on the other a fall of 3 inches in 100 feet, or ¼ of 1% along the terrace, was given. An increased yield of 15% in the level terraced area over the one given a fall was secured in 1926. In 1927, a year with a light rainfall distributed so as to produce a minimum water loss, 0.69% of the year's water supply was lost from the level terraced plat and 3.47% from the plat having a fall to the terrace. The increased yield in the level plat that year (1927) was 13% over the yield of the plat with a fall. In 1928 there was not sufficient soil moisture for planting until the spring rains started in the middle of May. From three rains that fell during the last of May and the first of June, totaling 2.71 inches, 12%, or 0.32 acre inch, was lost as run-off on the level terraced plat and 32%, or 0.87 acre inch, on the plat that had a slope of ¼ of 1% on the terrace.

The harvesting has not been completed, but the plat with the level terrace will yield as a conservative estimate from 30 to 40% more cotton this year than the one with a slope on the terrace.

Three years ago the best authorities on terracing recommended a fall of 3 to 12 inches per 100 feet along the terrace. Since the results of these experiments have begun to accrue, the level terrace is rapidly replacing the ones with a fall in sections with an annual rainfall under 30 inches and the fall given to terraces in sections with a heavier rain fall is being materially reduced.

Included in these 10-acre field areas is one that has been completely diked on the borders and a system of cross terraces constructed so as to hold all of the water that falls on the land. In 1927 this area produced 753 pounds of seed cotton to the acre, while a similar plat not terraced produced 646 pounds, or a difference of 107 pounds of seed cotton. The water loss from the plat not terraced in 1927 was 0.38 of an acre inch. In 1928 there was a loss of 1.05 acre inches from the rains the middle of May and first of June. The cotton harvested to date on the area not terraced amounted to 57 pounds of seed cotton to the acre, while on the area where all of the water was saved it has been 332 pounds to the acre. About one-half of the cotton on each plat had been harvested.

## SUMMARY

There are probably 50 million acres of land in Texas from which there should be no water lost as run-off. With a better understanding of the nature and character of the rainfall and with the development of practical methods of holding the water on the land where it falls, there will be more permanently anchored acres and the risk element of crop farming will have been materially reduced.

# 3. EROSION ON RANGE LAND[1]

W. R. CHAPLINE[2]

Maintenance of adequate watershed protection on forest and range lands is vital to the continued prosperity of the West. Five hundred and eighty-seven million acres of semi-arid and arid range land and 237 million acres of forest land in the United States are grazed. The forage on these lands is the foundation of the range livestock industry in which is invested nearly two billion dollars. Range forage furnishes 70% of the feed for all the livestock in the 11 western states. Water from the watersheds on which the forage grows furnishes the basis for extensive power developments and for irrigating nearly 20 million acres of farm land. Erosion, following depletion of the once dense carpet of herbaceous and browse plants, has not only seriously depleted the productivity of range lands but is also endangering established irrigation projects and making prospective ones uncertain.

Although numerous other factors influence erosion, of which climate, soil, topography, and geologic formation are doubtless the most important, the vegetative cover is the main single controllable factor. Because of its protective value, forest growth, including its understory of herbaceous and shrubby vegetation, should be maintained wherever possible on the head waters of all streams used for irrigation, power, or navigation. West of the 100th meridian, however, forests grow on only 13% of the land area. Herbaceous and shrubby vegetation must therefore afford the necessary protection to the soil and streamflow on the remaining 87%.

## EROSION AGENCIES

Annual rainfall is ordinarily scant and varies widely one year with another. Other climatic factors are also none too favorable for growth of vegetation. The vegetative cover, accordingly, seldom covers the ground completely, except under the more favorable soil and moisture conditions. The natural balance on these arid and semi-arid lands between the forces that tear down and those that build up the soil and vegetation is a delicate one, but if the vegetative cover is not excessively used erosion is usually slight. Natural agencies, such as drought, cloudbursts, landslides, and snowslides, may occasionally produce abnormal erosion. Man's activities, however, by reducing the vegetative cover or altering the topography

[1]Paper read as part of the symposium on "Soil Erosion" at the meeting of the Society held in Washington, D. C., November 23, 1928.

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or soil, can and do upset the balance completely. Once started erosion may develop to disastrous proportions.

Hydraulic mining along streams tears out the valleys and sides of gulches, leaving the debris in the creek beds for high water to carry down to fill the lower river channels or to spread like a wasting hand over fertile farm land. Smelters, an adjunct to mining, have depleted several hundred thousand acres of western range land and completely destroyed the vegetation on a considerable part of it.

The building of roads and trails, the cultivation of steep slopes without terracing, the draining of wet meadows to facilitate cultivation, and the straightening or changing of stream channels which have come about with settlement have caused serious erosion.

Fire has been one of the most important causes of erosion. In the early days of the white man's settlement of the West fires burned over enormous areas. Even when great effort is made to control them, fires destroy the vegetation on hundreds of thousands of acres in the West every year. A single prairie fire observed in the sand hills of western Nebraska in the spring of 1910 burned the grass from an area 100 miles long and up to 30 miles in width. With recurring fires, the stand of vegetation becomes more open, the length of time the ground is bare increases, and erosion becomes more active.

In the southern California brush fields which are protecting the watersheds the dense carpet of vegetation which required years to grow is often destroyed by fire in a few hours. These brush lands are valued as high as $1,000 an acre. When one stands in several inches of ashes on an extremely steep slope in the center of a burn, knowing that the humus, the life of the soil, has been consumed and that those ashes and the surface layer of soil will be washed down the slope with the first dashing rain, he realizes how great is the soil destruction from fire and erosion. Often several inches of soil are carried away after a fire. The problems of the influence of this brush cover on water supply and the effect of its elimination by fire is receiving intensive study by the Forest Service. A control dam in a small creek, put in before a fire occurred on the slopes above, required, after the fire, flash boards several feet in width on top of the old dam because of the deposit of silt in the settling basin. Silting of gravel beds is particularly undesirable because flood waters from well-covered slopes are sunk in these gravels to be pumped up later. If these flood waters carry an excess of silt, they fill up the pores and the water fails to sink.

Overgrazing has doubtless been the greatest erosion influence on range lands as a whole. Even before 1890 the ranges were badly overstocked. As numbers of livestock increased the palatable forage plants were grazed closer and closer, and their vigor was sapped. Instead of thick grass knee high, of which the early stockmen speak, there were shorter and sparser grass blades and stems; finally many of the plants gave up the struggle, and the stand was thinned. The less valuable plants were then grazed more severely, until they too were practically eliminated. The hungry animals in their search for feed trampled the range, destroying plant roots and packing the soil. The ranges became dust beds. Residents of Utah tell of being able to count the herds of sheep on the mountains by the dust clouds rising as the sheep trailed through the country. Under such conditions there was nothing to check the rain as it fell; the more compact soil could not absorb the water, which ran off and was quickly converted to a slimy mass of flowing mud. Shoestring gullies started and speedily gained depth, while the main drainage channels became raging torrents. The rich friable surface soil was washed away and the heavy clay subsoil exposed.

The regulation of grazing within the national forests and the consolidation of private holdings have greatly reduced the area of range overgrazed, but extensive areas throughout the West are still deteriorating through excessive or otherwise improper grazing use. The most serious situation at present is that on the 196 million acres of unappropriated and unreserved Federal lands with their unfenced, intermingled state and private lands, on which grazing can not now be legally controlled. Much of this public domain lies in the foothills and should furnish the abundant spring and fall feed essential to profitable livestock production. Drought and overgrazing, however, are seriously impairing the feed and watershed values of large expanses of these important Federal lands by robbing them, through erosion, of the soil material necessary to maintain a protective covering.

## EROSION LOSSES

This reduced productivity of range lands is doubtless the greatest loss occasioned by erosion. In their original condition the slopes and valleys, except in those arid parts where rainfall was very light, were well carpeted with valuable grasses and a small percentage of other herbaceous and shrubby plants. The decaying vegetable matter had built up the surface soil into a friable condition and added to it a large quantity of rich organic matter. The mulch of decaying vegetable matter acted as a sponge, and the friable humic character of the

soil allowed a maximum moisture penetration. The result was that the forage plants made the most of the rainfall and the fertile soil and produced abundantly.

With the top layer of soil removed the soil may become incapable of producing the stand it once supported. Experiments at the Great Basin Experiment Station in Utah showed that non-eroded soil was much richer than eroded soil in lime, phosphoric acid, and total nitrogen; that the water-holding capacity was greater; and that the water required by representative plants to produce a pound of drv matter was less. A great many more leaves, greater stem and leaf length, and more dry matter are produced on the non-eroded than on the eroded soil, even with a notably smaller supply of water. The conclusion was drawn that erosion is detrimental to plant growth chiefly because it brings about two conditions of soil impoverishment, *viz.*, (1) lack of adequate soil moisture for full plant development and seed production, and (2) lack of adequate plant nutrients in the soil for good growth. Furthermore, reestablishment of the vegetative cover is made more difficult. Because of lowered moisture content from soil exposure and lowered water-holding capacity on eroded soil supporting a thin stand of vegetation, seed germinates poorly and many of the seedlings die.

Thus improvement may be slow. An overgrazed slope in Utah which in 1910 had little if any herbaceous vegetation, scattered clumps of aspen, and soil eroding badly required 15 years to check satisfactorily the main erosion. By 1925, under regulated grazing, the aspen had spread materially by sprouting and the other vegetation on the slope now covers approximately 25% of the soil surface.

The type of erosion most readily recognized is the arroyo cutting of valley bottoms. Many of these arroyos are 10 to 30 feet deep and 100 feet or more in width, while the larger streams have cut deeper and still wider drainage lines. If no attempt is made to control the arroyo, it continues extending its tentacle-like arms back and up the draws by accelerating the flow of water over the falls at each finger's end, and saps the life from the valley and its tributaries by lowering the water table and tearing out the rich alluvial soil. The ultimate result is the cutting out of the entire valley floor.

Of 32 agricultural valleys in the national forests of Arizona and New Mexico, only 3, or less than 10%, had no erosion in 1923; 4, or 13%, had been ruined by erosion; 31% were partly ruined; and of the remainder 28% had noticeable erosion started. It is estimated that about 100,000 acres of agricultural land in these two states have been lost through erosion, nearly one-fourth as much as has

been reclaimed by the United States reclamation projects in the two states.

The more rapid run-off from the depleted, untimbered slopes, the greater quantities of silt carried, the quicker concentration of high water from small drainages into flood crests that eventually assume disastrous proportions cause the soil and vegetative depletion to play an important part in the distress occasioned in the main river valleys.

One of the worst features of floods is the enormous quantity of silt carried from the eroding slopes and rich valley bottoms along with rocks, bowlders, and other debris out on to valley farm lands or into irrigation and other reservoirs. Talbot reports an average deposit of 1 foot annually in 30 southwestern reservoirs used for livestock watering, making the average life for the reservoirs less than 15 years. Such a loss demands most urgent consideration of the silt problem. Over 9 feet of silt have been deposited when the lake was filled in an enormous blanket in the upper part of the Roosevelt Reservoir in Arizona. One flood alone washed out a considerable part of this and carried it down nearer the dam. Several hundred million dollars have been invested in the now prosperous Salt River Valley which gets most of its irrigation water from this reservoir. Unless excessive silting of this important reservoir can be controlled, its productive life will be materially shortened. The problem demands adequate study immediately. Under deferred grazing and correct utilization a number of washes several feet in depth on an experimental area on the Santa Rita Range Reserve in southern Arizona have been recaptured by grasses and brush. There is in addition a dense stand of grama on the slopes and no further cutting is occurring in the washes and erosion of slopes is negligible.

Check dams and other engineering works are used extensively in southern California where watershed values are very great. Small check dams may also be used to advantage to stop an arroyo from draining a meadow or when important watersheds are practically barren and vegetation is difficult to establish. Ordinarily, however, the reestablishment of the vegetative cover offers the cheapest and most practical means of reclaiming low-value range lands. Grasses and other vegetation will even gradually revegetate gullies formed from road ruts if they are given the opportunity.

## RESEARCH

The main range erosion control studies of the Forest Service are centered at the Great Basin Experiment Station in Utah. For the first five years both of the erosion study watersheds, which are

each approximately 10 acres in size, were grazed alike, and the stand of vegetation on them was kept stationary. Then, in 1920, one area was closed to grazing and revegetation was aided by seeding grasses, thus the vegetative cover was increased from an average of 16%, as at first, to 40% of the soil surface. The other area continued to be grazed so as to hold the vegetative cover at an average of 40%, just as it was at first. The run-off and sediment eroded from each area has been measured for each storm since 1915. The results, on a ratio basis between the two areas, show that after the herbaceous vegetation had improved until it covered 40% of the soil surface, the run-off from summer rains was 55% less and sediment eroded was 56% less than when the vegetation covered but 16% of the surface. Run-off and erosion from melting snow appeared to be affected much less by the change in herbaceous vegetation. Though approximately 95% of the annual run-off was from melting snow, it carried only 12% of the sediment removed; the 5% of run-off from summer rains carried 88% of the sediment eroded.

Since 1926, the area which was ungrazed since 1920 has been moderately grazed each year under a deferred system and the vegetative cover has further improved. A considerable part of the area, particularly the steep clay slopes, was almost barren or supported only a thin stand of annual weeds in 1915. Where the slopes are not so steep and the soil could be built up by annuals, a rather good stand of vegetation has come in. *Pentstemon* and sweet sage are especially good erosion control plants under the conditions prevailing on the area since they are not very palatable and they spread readily by root stocks. The seeds of grasses are washed down the little gullies along with some fertile soil and individual plants are gradually taking hold. Annuals also grow on the barren spots in favorable years.

Artificial reseeding has been rather successful for erosion control at the higher elevations. In the foothills, where because of past overgrazing palatable vegetation is scarce and slopes are eroding badly, only few cultivated plants have been able to withstand the severe climatic and soil conditions, although several native range plants have shown considerable promise. We must depend largely, however, upon natural revegetation by the native plants available on each range.

Plants not only lessen the force of rainfall but they and the mulch of decaying vegetation intercept part of it. The vegetation improves soil structure, allowing greater moisture penetration; it increases the water-holding capacity by increasing organic matter; it breaks

the effect of wind, binds the soil, and lessens sheet erosion; it obstructs run-off, reduces the velocity of flow and carrying power of the water; and by catching soil particles, it tends to form miniature terraces on slopes and may even dam and fill in small gullies.

The head of Manti Canyon, which lies just south of the station, was closed to grazing in 1903 because of the serious floods which came from the canyon through the town of Manti, Utah. At one time removal of the town to another site was under consideration. For several years the watershed was ungrazed and has been moderately grazed each year since livestock were allowed on it. Sheet erosion of slopes has been entirely controlled and most all gullies are now revegetated. No serious floods have come from the canyon since 1910.

Our research has indicated further that except where the vegetative stand has been practically eliminated and the exposed soil is seriously eroded, the native cover can ordinarily be restored under properly regulated livestock grazing almost as well and as quickly as under total protection from grazing. So far the range erosion research of the Forest Service has been confined largely to laying a foundation of basic and general information. It is essential that research determine just what is the optimum stand of vegetation that can be made to grow on the widely varying soil types and under the extreme climatic conditions of the West, and the influence of this vegetation on water supply. It is equally important to know more concretely just what grazing use can be allowed under each of the main range and watershed conditions to assure profitable livestock production and a maximum of protection to the soil. An important start has been made, but if it is to be of most value to the stockman, range-land owner, and water user. considerable enlargement is essential.

# 4. THE PREVENTION OF THE EROSION OF FARM LANDS BY TERRACING[1]

C. E. Ramser[2]

Soil erosion is due chiefly to the free movement of water over the ground surface. If most of the rain water were absorbed by the ground upon which it falls, erosion would be greatly reduced. It is obvious, therefore, that in order to prevent or reduce erosive action, the soil must receive treatment that is conducive to the admission and the storage of large quantities of the rain water. Methods must also be employed to reduce the velocity and thereby the transporting and erosive power of the run-off water.

It is the purpose of this paper to deal only with the prevention of erosion by terracing. According to the earliest practice, terracing consisted of building up the surface of the land in a series of level areas resembling stair steps. This type of terrace has long been used extensively in Europe, Asia, and South America, and is still being used to a considerable extent in the southeastern part of the United States. This terrace, commonly known as the bench terrace, has never become popular with the farmer because of the difficulty of moving farm machinery from one bench to another, the necessity of cultivating each bench separately, the loss of land occupied by the uncultivated embankment, and the growth of weeds and grass on the embankments.

The bench terrace has been rapidly disappearing from all lands of moderate slope, since the introduction of the broad-base ridge terrace which can be cultivated. This terrace is generally known as the Mangum terrace. It is built from 15 to 25 feet broad at the base and from 15 to 24 inches high and is given fall along the terrace to carry off the run-off water in a broad, shallow channel at a low non-eroding velocity. The principle involved in the design of this terrace is that the size and grade of the terrace channel be such that it will conduct the run-off water to a drainage outlet at a low velocity and without the possibility of the water overtopping the terrace.

The rainfall being the source of the run-off water, a knowledge of the amount, intensity, and duration of the rainfall; and the percentage of the rainfall that runs off is essential to the satisfactory design of a graded terrace system. The percentage of the rainfall that runs off depends upon the nature of the soil, the surface cover, the slope of the land, and the intensity of the rainfall. The results of experi-

[1]Paper read as part of the symposium on "Soil Erosion" at the meeting of the Society held in Washington, D. C., November 23, 1928.

[2]Senior Drainage Engineer, U. S. Dept. of Agriculture, Guthrie, Okla.

ments show that the heaviest rains produce the most erosion and the greatest percentage of the water that runs off, from which it follows that a terrace should be designed for the most intense rains that occur in order to be most effective against erosion.

An examination of many terraced fields with average soils revealed that not much noticeable erosion occurred on slopes between terraces for a vertical spacing of 3 feet on a slope of 5 feet in 100 feet, 4 feet on a slope of 10 feet in 100 feet, and 5 feet on a slope of 15 feet in 100 feet. It also showed that not much erosion occurs in terrace channels where the fall does not exceed 6 inches in 100 feet. The proper grade and vertical spacing of terraces for different soils and land slopes are subjects worthy of carefully planned experimental investigations.

Hydraulic formulas based on experimental data should be employed to compute the fall required for a terrace, the cross-sectional area of the terrace channel and the volume of run-off water being known. A common practice is to increase the fall at intervals along the terrace to accommodate the continually enlarging discharge from the increasing size of the drainage area. Such a terrace is known as a variable-graded terrace and is superior to a terrace with a uniform grade, since it removes the water with less erosion in the terrace channel and with less liability of the terrace being overtopped near the lower end due to the rapid concentration of the run-off water. Giving the terrace less fall near the upper end tends to hold back the upper water until the water below has had time to flow off.

In planning a system of terraces it is first necessary to locate suitable places for the disposal of the run-off water. Natural watercourses make the best outlets. In order to make the most advantageous use of natural drainage outlets and avoid the possibility of gullies developing at property lines it is often advisable for neighboring farmers to cooperate in terracing adjoining fields. Roadside ditches used as terrace outlets should be protected from erosion by means of paving or low dams to avoid injury to the road. Where natural draws are employed as terrace outlets, they should be seeded to grass to prevent the erosion of deep gullies.

A common cause of the failure of terrace systems is due to making the upper terrace in a field drain too large an area. As a result the upper terrace is usually broken during the first heavy rain and a large volume of water rushing down the slope breaks all terraces below. Failure to build terraces to the required height and cross-section at crossings of draws and gullies is also a very common cause of breaks in terraces. Terraces require considerable care and at-

tention during the first year before the loose soil has had time to settle thoroughly.

The old maxim, "What is worth doing at all is worth doing well," is particularly applicable to terracing work. Poorly terraced fields with glaring examples of bad breaks and accompanying gullies are no doubt largely responsible for the prejudice against terracing existing in the minds of many farmers.

In some sections of the country the opinion seems to prevail that successful soil conservation can be accomplished by proper farming methods and winter cover crops. The following quotation is taken from a report on soil erosion investigations in North Carolina by F. O. Bartel,

"By far the greater amount of erosion occurs during the summer months when the land is being cultivated. The results appear to prove that any system of cover crops will be only partially effective in stopping erosion unless it is carried through the summer. In order to stop the heavy loss during the summer where cultivation is being practiced, it seems evident that protection by terraces will be the only possible solution."

Terracing was first extensively practiced in the southeastern states. Since about 1915 the practice of terracing has been coming rapidly into favor in states west of the Mississippi River, and today perhaps the best terracing methods are employed in Texas and Oklahoma. That terracing is regarded as important and essential to the maintenance of land values in Texas and Louisiana is exemplified by the fact that the Federal Land Banks of Houston and New Orleans require that land subject to soil washing be terraced before granting loans.

## 5. THE NECESSITY FOR SOIL CONSERVATION[1]

A. K. Short[2]

Behind every progressive movement in every line of endeavor there is some motive to prompt the action. Business organizations seldom spend their time, money, and energy from a purely altruistic motive. More often such organizations lend themselves to those movements that tend to remove obstacles, or solve problems that are retarding progress, or that are slowing down the march to the goal of high efficiency that they desire which is, to give more safety and more stability to their business enterprises.

In the 11 years of operation of the Federal Land Bank of Houston there has been loaned approximately $175,000,000 to more than 60,000 Texas farmers. The money was obtained from the sale of Federal Land Bank Bonds, the payment of which is secured by mortgages on Texas farm lands. The directors and other officers of the Bank have accepted the trust and the obligation to see that the value is ample to secure the bonds that are sold against the land. The same responsibility and obligation continue as long as the loan is in force, or the bonds against the loan are in the hands of the bond buyers. The officers of the Federal Land Bank have accepted this as a sacred trust. They recognize that if Federal Land Bank bonds are to remain a safe and sound investment for the public the securities must be kept sound. It is recognized that if the farmer is to maintain his household in comfort and meet his obligations promptly he must maintain his security, which is soil fertility. I may say in passing that the Federal Land Bank of Houston is not alarmed as to the security in farm lands that are offered in our District, but a thorough study of the entire situation is being made and steps taken to prevent any alarm from ever becoming necessary.

In any section the average farmer plans to pay out his farm with some special type of field crop. Specialized field cash crop production does not lend itself to soil building or to soil conservation. Throughout our District, and as a matter of fact, throughout the entire South, cotton is the major crop grown to produce cash to meet financial obligations. Cotton is a clean culture crop and the land is left bare during the winter months, which are the months of greatest rainfall over the greater portion of Texas.

[1]Paper read as part of the symposium on "Soil Erosion" at the meeting of the Society held in Washington, D. C., November 23, 1928.

[2]Conservation and Terracing Agent, Federal Land Bank of Houston, Houston, Texas.

It has been pointed out by the Bureau of Soils that the United States as a whole is losing some 20 times as much plant food by water leaching and erosion as is being used by the crops that are produced. I have no doubt that with our mild winters, heavy rainfall during the winter when farm land is bare, the South is contributing a higher percentage of this enormous loss than any other section of the country.

As an illustration, we can study the acre production of cotton in Texas taken from the U. S. Dept. Agriculture statistics over a period of 60 years, 1866 to 1925. During the first 10-year period, from 1866 to 1875, the average acre yield of lint cotton was 236 pounds. During this period the greater part of the cotton of Texas was being grown on the fertile rolling sandy loam in the eastern part of the state. During the next ten-year period, from 1876 to 1885, the yield had dropped to 192 pounds of lint per acre. During this period the center of cotton production had moved further west, and the original fertile soils, without protection, had started washing. In the ten-year period from 1886 to 1895, the acre yield had increased to 198 pounds. It was during this period that the black land belt had its greatest development. During the next period, from 1896 to 1905, the yield was 169 pounds per acre. From 1906 to 1915, the acre yield had further decreased to 162 pounds. This decrease may be claimed by some as due to the boll weevil ravages which were worse during this period than any time before or since. However, this can not be substantiated because the decrease before and after this period was as great. The average of the last ten-year period, from 1916 to 1925, was 134.5 pounds of lint cotton per acre.

Recent figures indicate that we have not reached the low tide. The average yield for the seven-year period, from 1921 to 1927, was 129 pounds of lint cotton per acre. Some have claimed that the marginal land that is now being planted to cotton has a downward trend on the average production of the state. This is not the fact because the western lands that are rapidly being put under the plow are producing a greater average acre yield of cotton than are the older cotton lands where soil conservation is not practiced.

The decrease of 43% in acre yields of cotton in Texas over the 60-year period indicated was not wholly due to continuous cropping with cotton. Lint cotton takes practically no soil fertility from the land and the seed takes but little. It may be claimed that cotton root-rot in the black land section has done much to lower the average yield of cotton over the state. This is true, but it must be remembered that root-rot did not become a menace until continued cropping

and erosion exhausted the organic content of the soil. Some nine years ago, or two years after the establishment of the Federal Land Bank of Houston, the directors of the Bank realized the necessity of soil conservation and incorporated into the deed of trust the terracing requirement. This requirement is not optional with the borrowers but clearly sets forth the fact that if the Bank finds the farm is deteriorating and needs terracing, the borrower must terrace or the loan is called.

While to some this clause may seem arbitrary, it not only guarantees the security to the bond holder, but it saves the thoughtless farmer from himself.

We have long recognized soil conservation as one of the major farm problems of the farmer. We are just beginning to recognize that soil conservation is the greatest problem with which farm financing has to deal.

The Federal Land Bank of Houston created the Department of Soil Conservation and Terracing in May 1927. Up until this time the Bank had made but little effort to carry out the terracing program. In the organization of this new department of the Bank there was one of two courses to pursue. First, the enforcement of the terracing clause in the deed of trust, and second, an educational campaign for terracing, using the enforcement clause only when absolutely necessary. We are all coming more and more to the realization that the solution to all problems, including the farm problem, is information or education. The Bank chose the educational route, using the terracing clause to stimulate interest.

We recognized that the success of an educational campaign would be in direct ratio to the plans, organization, and cooperation pertaining to the campaign.

The Extension Service of the A. & M. College of Texas has been promoting terracing for the past 16 years. The 165 county agents have been carrying on a thorough and systematic pioneer educational work in soil conservation. As usual they had laid the foundation, established the truth by showing the vital necessity and the profits to be had from terracing. With all their effort along this line, and with their other duties, progress was slow. Here was an organized force of some 200 men who needed a stimulus to put over a program they deemed essential to the prosperity of our state. The Federal Land Bank of Houston decided to cooperate with the Extension Service of the College and join them in an organized statewide soil conservation program.

The request for meetings comes direct from the county agents to the Farm Engineer of the Extension Service in all counties where

county agents are located. In those counties without agents, the request comes from the secretary-treasurer of the National Farm Loan Association to the Conservation and Terracing Agent of the Bank. The itinerary is made out by the Farm Engineer and the Conservation and Terracing Agent of the Bank. In so far as possible, it is arranged so that the maximum work can be accomplished on minimum travel.

STATEWIDE TERRACING CAMPAIGN AND PROGRAM OF WORK[3]

The leaders of this campaign are the Extension Service of the A. & M. College and the Federal Land Bank of Houston.

There are three primary objects in view:

1. To teach more men and boys to use the farm level and to run terrace lines.
2. To impress upon farmers and business men the importance of soil and plant food conservation.
3. To demonstrate building an adequate terrace.

There are more than 465,000 farms in Texas. There are more than 300,000 that would be benefited by terracing. The majority of these farms must be terraced within the next few years or they will become so depleted of soil fertility that they cannot support the farm family. At the same time the farmers' purchasing power will be lowered and as a consequence business will suffer.

There are 165 county agents in Texas. With all other duties, and owing to the short terracing period, it is hardly probable that these county agents can average more than 50 farms per year. At this rate, it would take more than 35 years for the farms of Texas to be terraced.

All loan agencies of Texas have realized that land security can practically become worthless in less than 10 years from erosion. Throughout the entire state, farms are being washed away and deserted every year. This is an economic loss to the state and a destruction to our capital stock.

To get more farms terraced there must be more people trained in the fundamentals of terracing. Teach men and boys to run terrace lines under the county agent's or vocational teacher's supervision, then the agent's efficiency can be increased many hundred times.

The problem is to get the farmers to attend the school. This is mainly the problem of the county agent and the local secretary-treasurer.

(a) All members of the National Farm Loan Association in the county are notified from the Houston office of the place and the time of the school.

(b The local secretary-treasurer of the National Farm Loan Association should get in touch with the members of his organization and insist that they attend the school.

(c) In several instances the secretary-treasurer of the National

[3]This is sent to the county agent and to the secretary-treasurer of the National Farm Loan Association in the county where the terracing school is to be held.

Farm Loan Association has carried very effective advertisements in the local papers setting forth the benefits of the school.

(d) The county agent should carry news items in the local press for at least two weeks before the meeting.

(e) The business men should be asked to encourage the meeting by discussing it with their farmer customers and by display cards in their show window.

(f) In many instances the business men have cooperated by furnishing a sandwich lunch on the day of the school.

All publicity should be based on the place where the school is to be held and not on the demonstration. This meeting should be held where there is shade and water.

The local people should assume the responsibility of getting the people to meet at the time and place designated. After this, the responsibility rests with M. R. Bentley, Farm Engineer of the College, and A. K. Short of the Conservation and Terracing Department of the Federal Land Bank.

The forenoon at the school is used in teaching the fundamentals of setting up and adjusting the farm level and in running terrace lines.

Immediately after noon, M. R. Bentley, with charts displaying experiment station data, shows the rapid rate of soil washing upon different slopes of land and planted to different crops. The most desirable row system is explained, showing the effect upon soil erosion and upon water conservation. Models of soil saving dams and outlet controls are shown and their uses explained.

A. K. Short explains the effect soil erosion has on the farm family, the community, the business centers, and upon the future generation. A profitable and permanent system of farming is outlined from the experience of farmers. The attitude of the Federal Land Bank in regard to having their securities terraced is explained in detail.

Business men should be invited and encouraged to attend the afternoon meeting.

After the meeting, the crowd goes to the field to see the completed terrace.

A state representative of the Martin Ditcher Company attends each school. It is his aim to complete a terrace

The county agent and the local secretary-treasurer should locate a desirable piece of land for the demonstration. This should be near where the school is held but out of sight, so that it will not detract from the morning session.

A Martin ditcher should be located and power supplied. The power may be teams or tractor. The Ford Motor Company and the International Harvester Company have both cooperated in these schools. Any and all terracing implements and any and all kinds of power for terracing may be used. This is a terracing demonstration and only machinery being used for this purpose should be displayed.

The terracing lines should be run the afternoon before and all implements and power should be in the field not later than eight o'clock the morning of the school. We desire first to show a *completed* terrace, and second the implement that did it, and third how it is done.

The day is usually complete at 3:30 p. m.

This plan of holding terracing schools started in July, 1927. Up until September, 1928, we have held 150 terracing schools in 115 counties with a total attendance of 16,882.

We have held schools with large attendance and we have held schools with small attendance. In each and every instance the attendance has been in direct ratio to the interest the local people have taken in regard to the school.

# BARLEY VARIETY TESTS AT A HIGH-ALTITUDE RANCH NEAR OBSIDIAN, IDAHO[1]

Harry V. Harlan and F. W. Shaw[2]

The junior author of this article, if a man of seventy can be said to be junior to one in the forties, operates a ranch in the valley of the Sawtooth Mountains of Idaho. The valley is a cold one. Bush fruits, plums, and cherries can not be grown. Few garden vegetables are possible. Even peas are an uncertain crop. Here, as at other ranches similarly located, a small acreage of cereals would be highly desirable, if these crops could be grown. Attempts to grow cereals have been made for many years at the ranch. Continuous culture and selection have resulted in some progress.

In 1926, the authors found a mutual interest in expanding the experiments. The Office of Cereal Crops and Diseases is in possession of an extensive collection of barleys from over the world. It seemed probable that among them were sorts better suited to high altitudes than the chance varieties of the Rocky Mountain region. Accordingly, in May, 1926, an assortment of varieties was sent to the ranch for planting. Due to lack of information on the behavior of barleys under such conditions, the choice of sorts was far from being the best possible. They were chosen for earliness, the belief being that early-maturing varieties might escape the fall frosts. The fallacy proved to be in the fact that they were exposed to many frosts during the summer, for at this point frost may occur on any of the 365 days.

Early varieties are common in hot arid countries where their short season enables them to escape both heat and drought. The early barleys from Mariout, Egypt, and the Mediterranean generally were quickly shown to be unsuited to conditions in the Sawtooth. The same was true of the *deficiens* types from the secondary plateau of Abyssinia, and of the early barleys from the plains of India. The first lot, however, did contain one variety which was of much promise in itself and which gave a suggestion of value in the choice of sorts for future tests. This was an early barley which we have named Everest, because it was secured high on Mt. Everest by the Mt. Everest expedition. This variety stood the freezes well and produced a satisfactory yield of grain.

In 1927 a new lot of barleys was selected. This time we chose sorts from the high mountains and plateau regions along with a consider-

[1]Contribution from the Office of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture, Washington, D. C. Received for publication January 17, 1929.

[2]Principal Agronomist in Charge, Barley Investigations, and ranch owner and experimenter, Obsidian, Idaho, respectively.

able number from northern Norway and Finland. In this lot there were but one or two varieties which showed no promise. As a group the barleys from near the Arctic Circle were inferior to those from the high plateaus. Selections from the tropical highlands of Abyssinia were cold-resistant but late. The most promising varieties came from the highlands of Asia.

The unusual temperatures to which these barleys were subjected can be appreciated only by an inspection of the records. It will be seen in Table 1 that on 28 of the 31 nights of May the mercury went to freezing or below. Incidentally, the observations reported from Obsidian were secured from instruments located within 30 feet of the barley plantings. The average minimum for the month was 25°F. In June the average minimum was above freezing (33.4°), but even in this month minimums of freezing or lower were reached on 12 different dates. The lowest June temperature was 25°. July was the warmest month of the year 1927. The average minimum temperature was nearly 35°. Freezing temperatures were recorded on 13 days. The coldest temperature was on July 5, when the mercury reached 26°. The highest maximum for the month was 85° and the minimum for the same day was 33°. The early barleys commenced to ripen in the latter part of August. Colder weather came about the same time. On August 25, 27, and 31, minimum temperatures of 26°, 25°, and 22°, respectively, were recorded. Harvesting was not completed until September 19 after temperatures of lower than 20° had been experienced on three nights and freezing temperatures on several others.

Freezing temperatures do not affect all varieties alike. There is great variation in leaf injury. Everest is a very hardy variety, its leaves or culms being little affected. Freezing at certain stages does result in sterility of many flowers but seldom affects a whole head, indicating that in this variety the period during which a single flower is sensitive is of short duration. Some of the Norway barleys were resistant to leaf injury but very sensitive to spike damage at surprisingly early stages. In these varieties many spikes were completely killed when only half-formed and still far down in the boot.

The most valuable index of injury was suggested by Mr. Shaw. He maintained that the value of a variety depended more on the viability of the seed harvested than on yield. Table 2 shows the results of germination tests on the seed harvested. The variability is amazing and at once reduces the promising varieties to half a dozen. As would be expected the ones showing the greatest viability are usually early. This character is itself valuable and at once points to Pan-

nier, sometimes known as Kashgar, as being the most promising sort. It was not only the earliest variety but 94% of the seed produced was viable. Other outstanding varieties were Everest (C. I. No. 4105), Russia (C. I. No. 3963), and Mongolia (C. I. No. 4057). The Russian barley is of interest. It was early at neither Aberdeen nor Obsidian. While its lateness is undesirable, it was necessarily exposed to lower temperatures and is very resistant to injury. In fact, the correlation of earliness to germination in all varieties is only — 0.436 ± .0806, showing that some other late sorts were not more injured than some of the early ones. This can not but mean that Russia (C. I. No. 3963), the most outstanding example of resistance among the later selections, is valuable as a stock for crossing. The Mongolian variety is both hardy and fairly early, thus having two valuable characters.

TABLE 1.—*Daily maximum and minimum temperatures for the months of May to September, inclusive, at Obsidian, Idaho, in 1927.*

| | May | | June | | July | | August | | September | |
|---|---|---|---|---|---|---|---|---|---|---|
| Date | Max. | Min. | Max. | Min. | Max. | Min. | Max. | Min. | Max. | Min. |
| 1 | 47 | 29 | 55 | 27 | 68 | 30 | 70 | 32 | 53 | 36 |
| 2 | 40 | 9 | 59 | 25 | 73 | 40 | 68 | 33 | 70 | 33 |
| 3 | 45 | 18 | 58 | 33 | 70 | 42 | 70 | 30 | 70 | 36 |
| 4 | 41 | 17 | 58 | 30 | 56 | 36 | 74 | 33 | 60 | 42 |
| 5 | 45 | 18 | 65 | 28 | 65 | 26 | 78 | 31 | 69 | 27 |
| 6 | 48 | 27 | 70 | 32 | 75 | 28 | 77 | 35 | 66 | 34 |
| 7 | 41 | 29 | 75 | 34 | 78 | 32 | 73 | 36 | 48 | 19 |
| 8 | 38 | 25 | 63 | 37 | 80 | 34 | 73 | 30 | 53 | 18 |
| 9 | 47 | 19 | 63 | 36 | 75 | 35 | 76 | 30 | 49 | 30 |
| 10 | 49 | 26 | 65 | 34 | 77 | 31 | 71 | 46 | 48 | 30 |
| 11 | 50 | 29 | 68 | 32 | 78 | 34 | 75 | 35 | 56 | 30 |
| 12 | 50 | 26 | 68 | 31 | 70 | 32 | 54 | 40 | 62 | 28 |
| 13 | 61 | 25 | 62 | 35 | 71 | 32 | 57 | 35 | 45 | 33 |
| 14 | 69 | 26 | 63 | 35 | 68 | 31 | 58 | 39 | 40 | 27 |
| 15 | 71 | 29 | 65 | 29 | 67 | 28 | 63 | 32 | 58 | 18 |
| 16 | 73 | 30 | 65 | 35 | 75 | 29 | 70 | 30 | 67 | 22 |
| 17 | 61 | 37 | 66 | 40 | 79 | 32 | 72 | 33 | 70 | 24 |
| 18 | 48 | 20 | 69 | 36 | 85 | 33 | 78 | 32 | 72 | 24 |
| 19 | 46 | 31 | 62 | 33 | 81 | 35 | 75 | 40 | 74 | 26 |
| 20 | 39 | 19 | 68 | 29 | 80 | 32 | 71 | 40 | 74 | 26 |
| 21 | 38 | 24 | 73 | 29 | 80 | 34 | 76 | 36 | 72 | 26 |
| 22 | 42 | 24 | 74 | 41 | 80 | 36 | 75 | 31 | 73 | 29 |
| 23 | 43 | 26 | 68 | 34 | 80 | 38 | 73 | 28 | 68 | 31 |
| 24 | 52 | 32 | 71 | 38 | 75 | 45 | 70 | 33 | 59 | 25 |
| 25 | 63 | 33 | 79 | 33 | 72 | 42 | 70 | 26 | 58 | 31 |
| 26 | 53 | 33 | 59 | 42 | 77 | 38 | 60 | 30 | 63 | 25 |
| 27 | 48 | 27 | 58 | 30 | 78 | 44 | 73 | 23 | 64 | 26 |
| 28 | 44 | 24 | 63 | 34 | 73 | 43 | 73 | 39 | 53 | 32 |
| 29 | 38 | 23 | 64 | 39 | 73 | 36 | 105 | 42 | 42 | 31 |
| 30 | 46 | 20 | 60 | 31 | 69 | 40 | 58 | 38 | 42 | 29 |
| 31 | 49 | 21 | | | 73 | 32 | 64 | 22 | | |

TABLE 2.—*Observations on barleys grown at Aberdeen and at Obsidian, Idaho, in 1927.*

| Name or origin | C.I.No. | Date of awn emergence at Aberdeen | Obsidian Date harvested | Obsidian Percentage of germination of seed harvested |
|---|---|---|---|---|
| Finland | 581 | June 24 | Sept. 4 | 42 |
| Liland | 1323 | June 19 | Sept. 4 | 36 |
| Pannier | 2282 | June 14 | Aug. 22 | 94 |
| Alaska | 1395 | June 21 | Sept. 7 | 24 |
| Nakano Wase | 2275 | June 30 | Sept. 19 | 4 |
| Opdal | 2532 | | Sept. 17 | 24 |
| Asplund | 2533 | June 22 | Sept. 17 | 8 |
| Bjorneby | 2534 | June 22 | Sept. 16 | 14 |
| Donnes | 2535 | June 15 | Sept. 18 | 4 |
| Maskin | 2536 | June 16 | Sept. 11 | 52 |
| Trysil | 2537 | June 24 | Sept. 4 | 28 |
| Lapland | 2623 | June 23 | Sept. 14 | 48 |
| Feldnaer | 2624 | June 27 | Sept. 4 | 12 |
| Everest | 4105 | June 16 | Aug. 31 | 86 |
| Manchuria | 2330 | June 24 | Sept. 4 | 50 |
| Finland | 4211 | June 25 | Sept. 13 | 8 |
| Finland | 4212 | June 23 | Sept. 2 | 10 |
| Finland | 4213 | June 15 | Sept. 7 | 12 |
| Kashmir | 3873 | June 26 | Sep . 4 | 48 |
| Kashmir | 3883 | June 30 | Sept. 9 | 4 |
| Abyssinia | 3907 | July 7 | Sept. 17 | 8 |
| Abyssinia | 3912 | July 2 | Sept. 17 | 8 |
| Abyssinia | 3920–1 | July 1 | Sept. 17 | 40 |
| Abyssinia | 3920–2 | July 4 | Sept. 19 | 0 |
| Lapland | 2623 | June 23 | Sept. 19 | 20 |
| Alaska | 1336 | June 23 | Sept. 19 | 70 |
| Alaska | 1337 | June 23 | | |
| Alaska | 1339 | June 24 | Sept. 19 | 14 |
| Alaska | 2223 | June 28 | Sept. 19 | 10 |
| Alaska | 2228 | June 25 | Sept. 19 | 14 |
| Russia | 3974 | June 27 | Sept. 13 | 20 |
| Russia | 3982 | June 27 | Sept. 13 | 6 |
| Russia | 3963 | June 23 | Sept. 13 | 92 |
| Russia | 4001 | June 27 | Sept. 19 | 0 |
| Russia | 4005 | June 26 | Sept. 19 | 0 |
| Russia | 4006 | June 26 | Sept. 19 | 0 |
| Russia | 4008 | June 26 | Sept. 19 | 54 |
| Russia | 4009 | June 26 | | |
| Mongolia | 4047 | June 27 | Sept. 19 | 0 |
| Mongolia | 4054–1 | June 18 | Sept. 13 | 64 |
| Mongolia | 4055–1 | June 17 | Sept. 4 | 86 |
| Mongolia | 4056–1 | June 27 | Sept. 13 | 66 |
| Mongolia | 4057–1 | June 20 | Aug. 31 | 92 |
| Mongolia | 4062–1 | June 19 | Sept. 8 | 74 |

TABLE 2.—*Concluded.*

| Name or origin | C.I.No. | Date of awn emergence at Aberdeen | Obsidian Date harvested | Obsidian Percentage of germination of seed harvested |
|---|---|---|---|---|
| Mongolia | 4071-1 | June 27 | Sept. 17 | 12 |
| Mongolia | 4077-2 | June 27 | | |
| Mongolia | 4084-1 | June 27 | Sept. 19 | 0-10 |
| Shaw | | | Sept. 2 | 56 |
| Faust | | | Sept. 4 | 28 |

As a matter of passing interest it will be noted in Table 2 that there is no hard and fast relationship between the harvesting dates at the ranch and the emergence dates at Aberdeen. Emergence in this case means the emergence of the awn, an accurate statement of heading. The differences are mostly varietal reactions to temperature. The date harvested is not a fully comparative statement of conditions at the ranch. The date of harvest is modified by choice in deciding whether or not to await the maturation of the later culms. Also, the final date of September 19 is arbitrary, as continual freezing weather made further delay useless.

The performance of the barley here designated as Shaw is easier to evaluate after viewing the results with the other varieties. This barley is a hooded hulled sort evidently originating from a cross of Nepal on a six-rowed bearded variety. The Nepal comes from a considerable elevation on the southern slope of the Himalayas. It is suited to growing at high altitudes. It does not come from regions as cold as the native habitat of either Pannier or Everest. The Shaw variety, as originally grown at the ranch, was doubtless a mass residual of many heterozygous elements. It is certain that the barley as now constituted is much more hardy than it was when received. Where only small areas of barley are grown, and the farmers not ordinarily growers of this crop, a hooded or smooth-awned variety is highly desirable. The proportion of yield the average farmer is willing to sacrifice to avoid rough awns is inverse to the acreage. For these reasons it is felt that the Shaw barley can well be used as a foundation in hybrids where the object is to secure hooded sorts that are hardier than the best now available.

# EFFECT OF DATE OF SEEDING OF WINTER WHEAT ON PLANT DEVELOPMENT AND ITS RELATIONSHIP TO WINTERHARDINESS[1]

GEORGE JANSSEN[2]

## INTRODUCTION

With the continual advance of winter wheat culture into the northern United States there has come a great demand for wheat strains which are sufficiently hardy to withstand the vicissitudes of the climate, together with the inherent qualities capable of producing high yield and yet meet the demands of the miller. The importance of this problem has attracted the attention of both agronomists and geneticists, with their efforts directed largely in the search of new strains and varieties by hybridization and selection. Until very recently (23)[3] the task of locating winter hardy strains and varieties was a very difficult and time-consuming process, which ended frequently in disappointment. With the development of new methods for measuring the hardiness of a plant, it has become possible to determine with some degree of accuracy the capacity of varieties or strains to withstand cold weather.

Aside from the problem of producing hardy strains, various cultural practices have been employed in the production of winter wheat which have for their aim the ameliorating of plant growth so that the winter mortality may be reduced to the minimum. A review of literature (1, 2, 5, 6, 7, 9, 10, 16, 19, 24) on dates of seeding of winter wheat indicates that the stage of development of the wheat plant previous to the time it enters the dormant condition in the fall is of considerable importance and may determine its survival over winter. These investigations clearly indicate that the date at which winter wheat is sown in the fall greatly affects the winter mortality of the plant as well as the resumption of active growth in the spring. It appears that from a date of seeding standpoint a certain period must elapse from the seeding date till dormancy, during which time the plant must develop in preparation for the winter.

[1]This is the second part of a report on work carried on at the University of Wisconsin and submitted to the graduate faculty in partial fulfilment for the degree of doctor of philosophy. The first part was published in the February, 1929, number of this JOURNAL. Received for publication January 2, 1929.

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[3]Reference by number is to "Literature Cited," p. 464.

## OBJECT OF PRESENT EXPERIMENT

The investigations recorded in this paper were made with two principal objects in view. The first was an effort to determine the better dates of seeding from the winterhardiness standpoint. The second was an attempt to explain why certain dates of seeding of winter wheat result in greater returns than others as shown by experimental field data. An attempt will be made to correlate the morphological factors with the observed capacity of the plant to live over winter; and also to associate the possible effect of climate on the ability of the plant to survive the winter.

## METHOD AND MATERIAL OF INVESTIGATION

The present study was carried on with a pure line of Turkey wheat, Wisconsin Pedigreed No. 2. The wheat plants used for chemical analysis were taken from 1/40 acre test plats supervised by B. D. Leith on the University of Wisconsin experimental farm. Wherever samples were used in root or crown studies they were collected from the above plats. Analagous test plats were used for the purpose of obtaining grain yields. Root development studies were made on plants from all the date of seeding test plats. Seedings were made on or near the following dates: August 15, September 1, September 15, October 1, and October 15.

An experiment to determine the effect of variation in moisture supply on the plant with relation to hardiness was carried on in pots on two dates of seedings in 1922 to 1924. Soil moisture was controlled in these pots by weekly applications of water, sufficient to bring the pots to a definite weight. The pots were sheltered during rain and snow. The pentosan was determined according to the method described in a previous paper (12).

## RESULTS

### ROOT DEVELOPMENT

The root and crown development of the wheat plant is and has been of considerable interest to the agriculturist. The physical injuries to the plant due largely to insufficient root development have led to many cultural practices in the present farming system. The so-called "heaving" (28), the lifting of the plant from the soil by successively freezing and thawing and exposing the roots to the air, is partially prevented by a sufficeint root development of the plant. Late plantings which usually result in plants having a meager and shallow root system are very subject to "heaving." This "heaving" has been recognized by the practical grower as well as the scientist. Cultural methods, such as rolling the soil in the early spring (21),

sufficient depth of seeding (22, 23), and methods of planting (20, 28), mulching, etc., have been practiced with the aim of protecting the plant against "heaving" of the soil.

In view of the above knowledge on the value of a sufficient root system, it is of interest agronomically to study the root development from periodic plantings. The observations and data recorded on root development in this paper were taken from the date of seeding plats. These observations were made during two successive seasons. However, in view of the fact that the results both seasons were the same, results for one season only are reported.

Fig. 1 shows the relative amount of root development to a depth of 35 cm of plants from the second, third, fourth, and fifth dates of seeding. In all these instances it should be noted that there is proportionately as great difference in top and crown development as there is in the size of the root system. It is a physical impossibility to remove the plants from the soil with their entire root systems intact. To obtain more accurate data as to the rate of progressive root development, actual measurements were made of their depth at various intervals during the fall. These data, showing the progressive rate of root development of plants from the various dates of seeding, are presented in Table 1. These figures do not indicate the exact total depth to which all roots entered the soil, but relatively they do represent the depth of the majority of the roots.

The data presented indicate that the root development of the plants from the first date of seeding reached a depth of 35 cm. The plants from the second date of seeding had developed roots to a depth of 28 cm, as indicated by the final measurements made on November 26; while those from the third date of seeding attained a depth of 22 cm. It will be noted in Table 1 that in the case of plants from the third date of seeding the primary roots were practically as well developed as the secondary or coronal roots. Plants from October 6,

TABLE 1.—*Showing the depth of progressive root development of plants from various dates of seeding at various intervals during the fall of 1922, measurements being made on the average of 50 plants from each date of seeding.*

| Primary or secondary roots | Date measured | Length of roots in cm. at various dates of seeding August 18 | August 31 | September 21 | October 6 | October 19 |
|---|---|---|---|---|---|---|
| Secondary | October 29 | 20 | 20 | 1–6 | 0 | 0 |
| Primary | October 29 | — | — | 13 | 9 | — |
| Secondary | November 11 | 25 | 23 | 17 | 1 | 0 |
| Primary | November 11 | — | — | 17–20 | 12 | 9 |
| Secondary | November 26 | 35 | 28 | 22 | 2 | — |
| Primary | November 26 | — | — | 20 | 19 | 12 |

the fourth date of seeding, had only the beginning of a secondary root system on November 26, though the primary roots extended into the soil to a depth of 19 cm. Plants from the fifth seeding showed no secondary root development whatsoever in the fall, and even the primary root system was poorly developed.

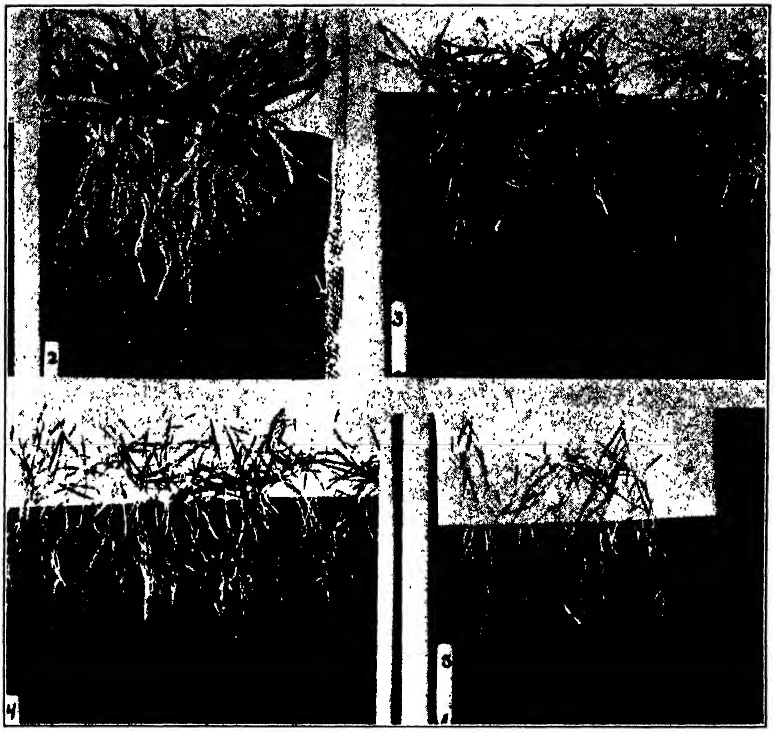


FIG. 1.—Root development of winter wheat plants taken from the date of seeding test plats. The seedings were made on the following dates: 2, Sept. 4; 3, Sept. 18; 4, Oct. 4; and 5, Oct. 17.

Care must be taken when speaking of winterhardiness not to confuse the actual hardiness of the plant due to some physiological and chemical constitution of the plant, which enables it to resist low temperatures, with the escape from or protection against mechanical injury to the plant, i. e., fracturing and tearing of the root system caused by environmental conditions. This escape from mechanical injury, and therefore possible escape from death by this means, may be brought about partially by the proper development of the root and crown of the plant. The data on the root development, together with Fig. 1, clearly show that from the standpoint of crown and root

development the plants from the August and September dates of seeding could more successfully resist unfavorable environmental conditions than could those plants from the later dates, namely, October and November seedings. It must be understood, however, that the actual percentage of winterkilling in the case of early seeding

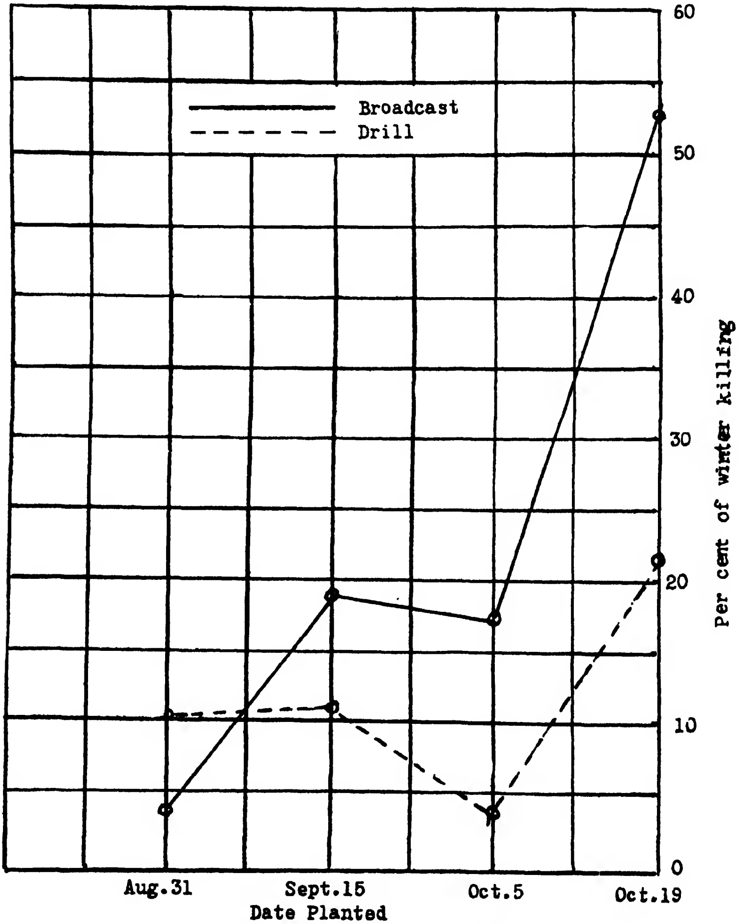


FIG. 2.—Percentage of winterkilling of plants on drilled and broadcasted winter wheat test plats during the winter of 1922–23 for four dates of plantng.

(middle of August, Figs. 2 and 3) does not conform to the degree of root development, therefore, we must look for other causes. Some of these causes have been discussed in another paper (12).

It has been observed repeatedly that plants from the late dates of seeding usually succumb to unfavorable weather and soil conditions.

Alternate freezing and thawing of the soil is especially injurious to the plants of these late seedings. It is not uncommon in the spring to find plants which have only a primary root development with

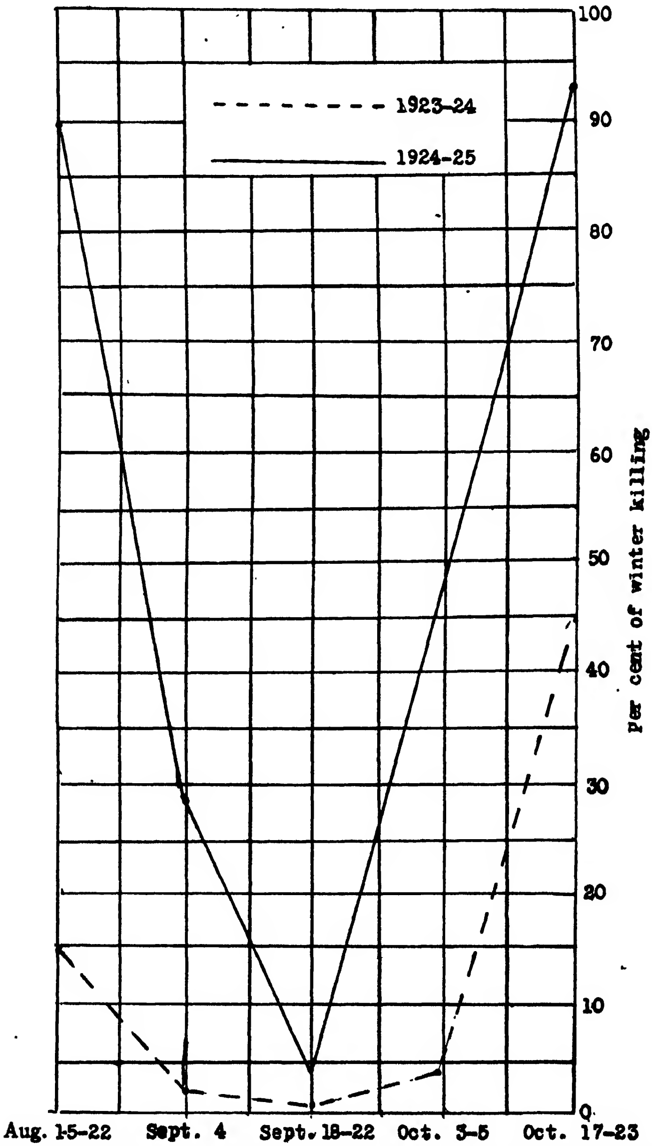


FIG. 3.—Percentage of winterkilling of winter wheat during the winters of 1923-24 and 1924-25 for five dates of planting in the fall.

many or all of these roots broken, and consequently the plant is detached from the soil. Frequently, if a few roots remain attached to the soil, the plant will recover from such injurious effects, provided the spring season is humid and that the surface soil is moist so that the plant may not dry out but exist until it is able to form a permanent root system. Such lifting of the plants from the soil and subsequent desiccation of the plant crown seldom occurs in the earlier seeding. It should be borne in mind, therefore, that within certain limits, early seeding, which ultimately results in a well-developed plant, is advisable, though, as will be pointed out later in this paper, seeding at either extreme of the season is disastrous to the plant.

Though the killing of the plant purely by physical and mechanical injury due to environmental cause and poorly developed crown and root systems cannot be considered under the subject of hardiness or cold endurance, it certainly must be regarded as an important factor in the economic production of winter cereals. It is difficult to say whether the fracturing of the root system and the exposure of the crowns to the air caused all of the winterkilling in the fourth and fifth dates of seeding noted in Figs. 2 and 3 as a consequence of insufficient root development as shown in Fig. 1, or whether other conditions influenced the winterkilling. It is pointed out in a previous paper (12) on the chemical composition of the plant that the quantity of reserve substances in the crown of the plant in the fall and the rate at which these substances are respired in the dormant season very likely bear an important relation to the survival of the plant over winter and its subsequent spring recovery.

## CROWN AND SHOOT DEVELOPMENT

Considerable variation was noted in the development of the plants from the various date of seeding plats. This variation and degree of development as evidenced by the size of the crown and shoot is not constant over any number of seasons but is subject to great fluctuations depending upon the seasonal environmental conditions, especially climate and soil. The importance of the soil, particularly the soil moisture, in influencing the crown and shoot development was observed in the experiments conducted with winter wheat plants grown on soil maintained at various soil moisture percentages. In general, the results of this experiment indicated that a range of soil moisture content from 10 to 25% based on dry weight of soil is instrumental in bringing about a xerophytic or a mesophytic type of growth in plants from any date of seeding.

Fig. 4 shows the relation of air and soil temperatures and precipitation to plant development during 1923 to 1924. This chart reveals the fact that in the fall of 1923 the precipitation during the critical growing period of winter wheat was considerably greater than it was during the same period of 1924. Similarly, the average daily temperatures for 1923 were relatively higher than those for the same period of 1924. Under these conditions, it is to be expected that the character and type of plant development would be different for the two fall seasons of 1923 and 1924. In the fall of 1923, a


FIG. 4.—Soil and air temperature for the winters of 1923–24 and 1924–25, together with the precipitation for 1923–24. The daily temperatures are the average of the maximum and minimum ranges within each 24 hours.

luxuriant vegetative growth was produced, especially on the early dates of seeding, while in the fall of 1924 such a rank growth was not noted. In this last year the plants from all the dates of seeding had a prostrate xerophytic growth habit. This type of growth was especially pronounced in plants from the second and third dates of seeding. A much heavier development of crown in proportion to the leaf area was evident in plants from the intermediate dates of seeding than in plants from either the first or last seeding. Not only was the crown much smaller in the plants from the first seeding than it was in those from the second and third seedings, but the plant as a whole assumed a more erect habit of growth simulating that of a spring

variety. In the fall of 1923 the plants from the first seeding actually began to joint, and in place of the natural decumbent growth habit an erect, active-growing plant was obtained. The plants from the fourth seeding formed little or no crown development in that year.

In spite of the fact that environment greatly influenced or modified the type of plant growth on the various dates of seeding plats, in general there seemed to be a distinct difference in the plant development between the different dates of seeding for either of the seasons. The plants of the first seeding usually produced the greatest top growth, frequently more or less erect in habit, accompanied by a small to intermediate crown development. The plants as a whole tillered considerably. The growth of tops decreased progressively from the first to the fourth seeding, and, with the exception of the fourth seeding, the crown growth increased in proportion to the leaf area. The coronal roots on the late dates of seeding did not appear in the fall of the year. These plants formed a long, slender, sub-crown internode which enlarged slightly at, or near, the surface of the soil. It is at this enlargement that the coronal or secondary roots emerge the following spring. The plant as a whole was exceedingly small and tender and might easily be fractured by a longitudinal pull, such as is exerted by "heaving" due to freezing of the soil. (See Fig. 5 C.)

The argument made by many writers that an exceedingly well-developed crown system of the wheat plant is beneficial as a physical protection to the plant is true, since it equalizes soil temperatures and prevents rapid fluctuation in the temperature of the plant. The writer observed repeatedly that in the spring of the year the disappearance of the frost from the soil of the earliest-planted plats was delayed four or six days or more over the disappearance of frost from the soil of the late-seeded plats. This condition is due entirely to the fall top growth of plants which acted as a mulch in preventing rapid thawing. This action of the dead leaf mulch therefore may act to equalize the temperature and afford protection to the plant against rapid temperature changes. This observation relative to the increased leaf covering must not be regarded as having the equivalent properties of a snow covering or an artificially applied mulch. Excessive leaf area is usually accompanied by a large amount of winter killing, this portion becoming a loss to the plant so far as synthesized or stored food material is concerned. Freezing to death of the leaf tissue may result in the other tissues adjoining the dead area becoming more permeable and hence subject to subsequent leaching, and this also opens excellent avenues for bacterial and fungal invasion.

This was particularly true for the spring season of 1924. Thus, in spite of the fact that the leaf area may act as an equalizer of temperature changes, it may become harmful in the spring development of the plant as a whole.

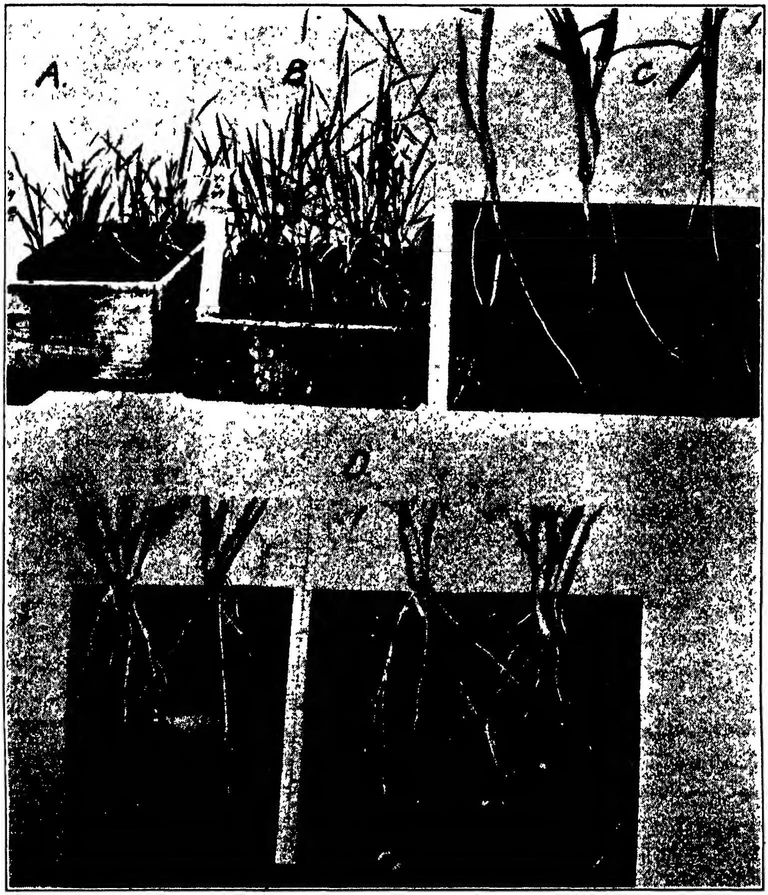


FIG. 5.—A and B, plants taken from the field in a frozen state on April 2 and treated as follows: A, transplanted after removing all roots and leaves, leaving the crown intact; B, transplanted without removing any portion of the plant. C, sub-crown internode injury due to freezing and thawing. D, formation of new spring roots at the crown only.

## SPRING PLANT DEVELOPMENT

*Root development.*—Preliminary observations were made on the spring root development of the winter wheat plant by J. G. Dickson and B. D. Leith of the Wisconsin Experiment Station in 1920 and

1921. They noted that new roots were usually sent out from the crown of the plant early in the spring of the year. A more extensive study was undertaken by the writer in the fall of 1922. Plants were taken from the field in a frozen condition on February 2, 1923, and replanted in moist soil in the greenhouse and allowed to develop. The plants were watered with a balanced nutrient solution. It was noted that the most healthy and vigorous roots developed on plants collected from the third seeding test plat. All new roots developed from the crown of the plant. Elongations of the roots previously formed or secondary branching did not occur. The early spring development of new roots on plants in the field from the third date of seeding is shown in Fig. 5, D. This shows conclusively that the new roots originate from the crown of the plants and not, generally, from the continuation of old root growth as is commonly assumed.

As new spring roots develop readily from the crown of the winter wheat plants, it might be assumed that the old roots could be cut away from the plant and still not greatly retard its development. An experiment of this nature was undertaken in the spring of 1923. Plants from the third date of seeding were removed from the field on February 8 and on March 2 when the ground was frozen, and taken to the greenhouse where they were treated in the following manner: One lot of plants, which were used as checks, were transplanted without removing either roots or tops. A second group was replanted after the tops and roots were cut away leaving the crowns which were about one-half inch in length. These plants were allowed to develop in the greenhouse at a temperature of 16°C. Fig. 5, A and B shows these plants after they had begun to joint. It will be noted that there is little or no difference in recovery between the control plants and those which had their roots and tops cut away.

To substantiate this finding a test was made with the aim of determining what effect root pruning would have upon field plants from the standpoint of plant growth as well as the relative subsequent vigor of the plants. Hence, immediately after the frost had gone from the soil the roots of plants from a portion of the third date of seeding test plats were cut away. The cuts were made immediately beneath the crown of the plant with a sharp, long-bladed knife. This treatment at the time of cutting in no way dislodged the plant from its natural position in the soil. The results from this test indicated that the subsequent development and growth of the plant after treatment was slower by 2 or 3 inches during its entire stage of plant development than the control plants. No difference could be noted in the ultimate size and growth of the treated and untreated plants.

After heading, approximately 60 to 90 of the treated and untreated plants were selected at random and the number and length of each spike per plant determined. The averages of these results are given in Table 2. It will be noted that there is no difference in the number of heads per plant, or in the length of the spikes, between the control plants and those which had their roots cut. The length of spikes was a little greater in the plants with roots cut, but the difference comes within the range of experimental error.

TABLE 2.—*Showing the effect of early spring root cutting upon the average length of spikes and the number of spikes per plant on plants from the second and third dates of seeding.*

| Planting | Number of plants | Number of spikes per plant | Average length of spikes in cm |
|---|---|---|---|
| | Second Planting | | |
| Roots cut | 62 | 2.250 | 2.020 |
| Roots not cut | 90 | 2.377 | 2.280 |
| | Third Planting | | |
| Roots cut | 85 | 2.950 | 2.416 |
| Roots not cut | 66 | 2.710 | 1.640 |

*Crown and shoot development.*—Early development of the plant in the spring varies for the different dates of seeding. This particular variation depends on the spring season and on the spring condition of the plant. In the spring of 1923, the plants from the early seedings were slow in recovering from injuries received during the winter. Spring shoot development and rate of growth was very irregular within the same plat.

It has been shown (10) that usually the tiller buds of winter wheat plants are formed on the plant in the fall of the year. The writer has noted that these tillers do not continue to grow and develop the following spring at an equal rate on the same seeding and even on the same plant. In many instances some of the buds or tillers on a plant do not continue growth, while others start growth but eventually die. Hence, it is not uncommon in the spring to find that on the same plant some of the tillers grow vigorously, whereas others do not even begin their growth. This condition was noted in the spring of 1923 in plants from the first seeding and, as the result of such a condition, the field took on a patchy and ragged appearance entirely different from the uniform and natural healthy green color found in fields of the later dates of seeding. In the spring of 1924, the plant development from the early dates of seeding was equal to that of the intermediate seedings. In that year the very late seeding test plats appeared ragged and patchy and exhibited a very irregular growth development and plant recovery, whereas the plants

from the early seedings developed much more rapidly and more uniformly.

It appears from these observations that the crown and shoot development is greatly influenced by environmental conditions in the fall. This ultimately tends to determine the type of plant, and its capacity of living over winter. The spring environmental conditions again may greatly alter or influence the spring development of the plant. This, together with the variable conditions of the plant in the spring as a result of over-wintering, is largely responsible for such lack of uniformity of spring habit of growth from year to year.

One point should be brought out here with respect to the development of crowns and shoot, and that is with reference to the development of disease. Leaf rust, Septoria, *Gibberella Saubinetti*, and mildews are especially abundant on plants in the early dates of seeding. The added shoot growth, succulent in character, forms an excellent host medium upon which these parasites can develop and increase as well as live over winter. The increased winter injury to the leaf area of plants from the first seeding over that of plants from the later seedings makes the chance of infection a great deal easier in the plants from the earlier seeding, also the larger amount of leaf rubbish present in the field of the first seeding on which the organisms may grow and sporulate as a saprophyte greatly increases the chance for the infection of plants the following spring. In this connection it may be stated that in the fall of 1923 Septoria infection ranged from approximately 50% of the leaf area on plants from the first seeding to but a few per cent on plants from the later seedings. The range in percentage of early spring infection on plants from the early and late seedings was more pronounced than in the previous fall, but as the season advanced plants from all seedings became equally infected.

From the foregoing observations it is evident that the spring recovery of the plant must be considered of fundamental importance to its proper development. It has been noted that not only is there a difference between the capacity of plants to recover in the spring when they have obtained various degrees of development during the previous fall, but that this recovery is greatly increased or inhibited, depending upon the spring environmental conditions to which the plant is subjected. Aside from the direct effect of the environment upon the plant, it has also been noted that from the standpoint of disease the environment may be an indirect factor in bringing about decreased yields in winter cereals which factor, however, varies with plants from the different dates of seeding. Thus, judging

from the standpoint of development in the fall alone, or from the recovery of the plant in the spring, one is confronted with a multitude of factors, all of which must be critically analyzed before specific conclusions regarding winterkilling can be made.

## YIELDS OBTAINED FROM VARIOUS SEEDING DATES

Table 3 gives the comparative yields obtained from the date of seeding test plats with two rates of seeding for the three consecutive years, 1922 to 1924 inclusive. It will be noted that in 1922 the best yield was obtained from the first seeding when a 1.5-bushel rate of seeding was used, and the last of September when the 2-bushel rate was used. No notes were taken on development of the plants from the various dates of seeding during this year, but it is evident from the yields that the percentage of winterkilling was greater, or else plant recovery in the spring was less, on the first and last seedings than on the intermediate seedings.

In 1923, the largest yields were obtained from the intermediate and late plantings. In that year the 1.5-bushel rate of seeding made in the first week of October yielded 66.4% more than the least favorable date, namely, the first part of September, whereas the yield for the 2-bushel rate was 58.7% greater for the former seeding than that of the latter. This correlates directly with the percentage of winterkilling on the various dates of seeding for that year.

TABLE 3.—*The comparative yields of winter wheat for three consecutive years obtained from the date of seeding test plats when two rates of seedings were used.*

| Year | 1.5 bushels per acre | | | | | 2 bushels per acre | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Last of Aug. | First of Sept. | Last of Sept. | First of Oct. | Last of Oct. | First of Sept. | Last of Sept. | First of Oct. | Last of Oct. |
| 1922 | 9.1 | 13.5 | 11.6 | 8.8 | killed | 12.3 | 13.6 | 11.2 | killed |
| 1923 | 11.2 | 8.6 | 19.2 | 25.6 | 24.3 | 12.3 | 17.0 | 29.9 | 26.2 |
| 1924 | 31.4 | 31.3 | 27.9 | 21.7 | 10.4 | 29.8 | 31.4 | 29.0 | 6.7 |
| | | | | Average | | | | | |
| 1922–24 | 17.2 | 17.8 | 19.5 | 18.7 | 11.5 | 18.1 | 20.7 | 13.03 | 10.9 |
| 1918–24* | 23.8 | 25.3 | 23.8 | 21.1 | 15.5 | 23.9 | 25.9 | 24.1 | 15.3 |

*Data taken from manuscript prepared by B. D. Leith of the Agronomy Department.

The averages of the three-year test for both the 1.5- and 2-bushel rate of seeding show that the better period for seeding winter wheat from a yield standpoint is during the latter part of September. The yields from a seven-year average, 1918 to 1924 inclusive, obtained from the date of seeding test, show that for the 1.5-bushel rate of seeding the better date to sow winter wheat at Madison,

Wisconsin, is during the first part of September, whereas results obtained for the 2-bushel rate point to the last part of September or the first of October as the best period. These data directly correlate with the percentage of winterkilling obtained in the three years, 1923 to 1925 inclusive. In all cases the very early and very late seedings, the last of August and October, always reduced the final yield.

## PERCENTAGE OF WINTERKILLING

It has already been stated that winterkilling of winter cereals may be due to several factors, any one of which may become serious. Whether or not any factor will manifest itself is dependent entirely upon the environmental conditions. The hardiness of the plants from the various dates of seeding was determined from the survival of plants in the spring after growth had been resumed. The percentages of winterkilling of plants from these various dates of seeding are shown in Figs. 2 and 3.

It must be understood that any system of taking plant stand records is open to criticism. In these particular instances the results were obtained by counting the number of plants within the area of 1 square meter. This was done in the fall and again in the spring of the year when the plants had attained a sufficient growth so that the individual plants could be distinguished. The areas counted in the fall were marked, and the plants in these same areas were recounted the following spring. Six countings were made on each date of seeding.

Mention should be made of the fact that the winterkilling percentages were determined on both drilling and broadcasting in 1922. In general, the percentages of winterkilling of plants, when these two methods of seeding were employed, were the same, but more winterkilling of plants was noted in some cases on the broadcast seeding for the late plantings which can be attributed largely to an insufficient root development. (See Fig. 1.) The seed, being sown on the surface of the soil, had little time before frost to develop a root system by which it might anchor itself in the soil. Thus the plant, undergoing freezing and thawing, was separated from the soil which naturally led to its desiccation and eventual death.

The percentages of winterkilling which occurred when the seedings were made with a drill as shown in Fig. 3 are self-explanatory. It should be stated here also that the high mortality in the late dates of seeding, October 5 and especially October 23, in large measure was not due to an actual killing of the protoplasm during the winter, but to a killing of the plant by "heaving" in the spring. These

plants, having a very shallow root system, were subjected to "heaving" and the roots were sometimes raised out of the soil entirely or at least were badly fractured. This type of heaving in the late seedings is different from the cutting of roots of an older plant. The injury is perhaps not due so much to root fracturing and tearing as to the separation of the plant from the ground. This leads to an early and rapid drying out of the crown, and eventually to the death of the plant unless the spring is humid and there is sufficient moisture in the upper few inches of the soil so that the plant may form new roots and reestablish itself firmly in the soil. Dry conditions in the spring of 1923 and 1925 caused approximately 50% killing on the late seeded plats. The fall stands obtained on the very late seeding of October 1923 were approximately 50% of those obtained on the other earlier dates of seeding. It will be seen, therefore, that when 90% of this seeding killed out, as it did in 1924 to 1925, the number of plants remaining in the spring would be very small.

### SOIL MOISTURE CONTENT

The soil type and moisture content greatly affect the course of development of the winter wheat plant during the fall and its ability to resist frost in northern climates. This phase of the problem has been reported by different authors (6, 11, 21). In general, the results of these workers indicate that a heavy clay soil is unfavorable to the culture of winter wheat in regions of high humidity. These conceptions are based largely upon the physical effect on the plant as a result of "heaving" of the soil. The temperature variations in different soil types have been recorded (26, 27). Variations in temperature occur in dry and moist soil (28) under similar atmospheric temperatures, although actual statistics on this phase of work seem to be lacking. Magistad (18) has determined the depression of the freezing point of sap from the wheat and corn plant resulting from the application of mineral fertilizers to the soil upon which the plants were growing. He concludes that the depression of the freezing point of the plant sap corresponds directly to the amount and kind of fertilizers applied to the soil.

The above experiments show clearly that resistance of plants to low temperatures depends in part on the physical condition, as well as on the chemical composition of the soil. With these facts in mind it is only natural to assume that the moisture content of the soil would have as great an effect on the development and composition of the plant as do soil nutrients, since chemical reactions and rate of plant growth are influenced by the amount of moisture present. Certainly it plays a large part in determining the physical condition of the soil.

These facts are brought out especially in a review of literature on water requirements of plants by Briggs and Schantz (4).

An experiment was conducted from 1922 to 1924 to test the effect of soil moisture on the winter survival and spring recovery of wheat plants in two stages of development. The plants were grown in cans 10 inches in diameter and 10 inches deep, each holding approximately 17 kilos of soil. Two series of plantings were made in two successive years, 1922 and 1923. Four series of moisture contents were used, *viz.*, 10, 15, 20, and 25%, based on the dry weight of the soil. Thirty seeds were planted in each can. Weekly applications of water equivalent to the moisture lost through evaporation and transpiration were added to the cans. The cans were kept in the open from the time the seed were planted, with the exception that they were sheltered when it rained or snowed. This precaution was taken in order to make conditions, other than soil moisture, comparable with plants growing under field culture.

TABLE 4.—*Effect of soil moisture on the development of the wheat plant in the fall, winter survival, and recovery in the spring as shown by plants grown in cans planted September 14, 1922.*

| Can No. | Water content | Fall stand | Height of plant, cm | Spring stand | Spring recovery |
|---|---|---|---|---|---|
| | % | % | | % | |
| 1 | 10 | 90 | 9 | 90 | Excellent |
| 2 | 10 | 90 | 10 | 90 | Fair |
| 3 | 10 | 50 | 8 | 45 | Fair |
| 4 | 10 | 55 | 10 | 50 | Fair |
| 5 | 10 | 100 | 8 | 100 | Excellent |
| 6 | 10 | 100 | 10 | 100 | Excellent |
| 7 | 15 | 100 | 15 | 100 | Good |
| 8 | 15 | 95 | 15 | 0 | Ice sheet |
| 9 | 15 | 60 | 15 | 0 | Ice sheet |
| 10 | 15 | 65 | 15 | 0 | Ice sheet |
| 11 | 15 | 100 | 18 | 0 | Ice sheet |
| 12 | 15 | 100 | 18 | 100 | Good |
| 13 | 20 | 100 | 18 | 95 | Fair |
| 14 | 20 | 100 | 18 | 95 | Fair |
| 15 | 20 | 75 | 18 | 70 | Fair |
| 16 | 20 | 70 | 18 | 70 | Fair |
| 17 | 20 | 100 | 18 | 95 | Fair |
| 18 | 20 | 95 | 19 | 95 | Poor |
| 19 | 25 | 95 | 19 | 95 | Poor |
| 20 | 25 | 95 | 18 | 80 | Poor |
| 21 | 25 | 60 | 18 | 50 | Poor |
| 22 | 25 | 60 | 19 | 50 | Poor |
| 23 | 25 | 100 | 19 | 80 | Poor |
| 24 | 25 | 100 | 25 | 50 | Ice sheet |

The results for plant recovery and relative hardiness, or ability of the plant to live over winter, when grown on soil having different controlled moisture percentages, are presented in Tables 4 and 5. Table 6 shows data from two seedings of winter wheat made in the field on soil areas of 10 square feet. These areas were protected from precipitation by a canvas top on days when it rained or snowed. Soil samples were taken at intervals of one week each. The amount of water which was necessary to bring the soil moisture of the first surface foot of soil to the moisture percentage indicated in the table was calculated and the water applied by weekly applications.

TABLE 5.—*Showing the effect of soil moisture on the development of the wheat plant in the fall, winter survival, and recovery in the spring as shown by plants grown in cans planted October 10, 1922.*

| Can No. | Water content | Fall stand | Height of plant, cm | Spring stand | Spring recovery |
|---|---|---|---|---|---|
| | | | | % | |
| 1 | 10 | 100 | 9 | 100 | Excellent |
| 2 | 10 | 100 | 9 | 100 | Excellent |
| 3 | 10 | 100 | 10 | 98 | Excellent |
| 4 | 10 | 100 | 10 | 99 | Excellent |
| 5 | 10 | 100 | 11 | 100 | Excellent |
| 6 | 10 | 95 | 10 | 95 | Excellent |
| 7 | 15 | 95 | 10 | 94 | Good |
| 8 | 15 | 100 | 10 | 99 | Good |
| 9 | 15 | 95 | 11 | 95 | Good |
| 10 | 15 | 100 | 11 | 99 | Good |
| 11 | 15 | 100 | 12 | 100 | Good |
| 12 | 15 | 100 | 13 | 98 | Good |
| 13 | 20 | 95 | 12 | 95 | Good |
| 14 | 20 | 90 | 13 | 70 | Fair |
| 15 | 20 | 90 | 13 | 89 | Fair |
| 16 | 20 | 100 | 13 | 68 | Poor |
| 17 | 20 | 90 | 13 | 90 | Fair |
| 18 | 20 | 90 | 13 | 89 | Fair |
| 19 | 25 | 95 | 15 | 50 | Poor |
| 20 | 25 | 98 | 15 | 72 | Poor |
| 21 | 25 | 100 | 15 | 90 | Poor |
| 22 | 25 | 100 | 16 | 66 | Poor |
| 23 | 25 | 100 | 16 | 75 | Poor |
| 24 | 25 | 100 | 16 | 65 | Poor |

The results given in Tables 4, 5, and 6 indicate that plants which were grown in soil of low moisture content lived through the winter in better condition and recovered better in the spring than those growing in soil with higher moisture content. No important difference was noticed in the recovery of the plants from the two dates of seeding. It should be noted, however, that both dates of seeding,

September 14 and October 10, were favorable for good plant development.

The emergence and rate of plant growth was markedly different for plants growing in soil having different percentages of moisture. In general, the rate of fall growth was the same comparatively for both dates of seeding, but the earlier seeding naturally developed to a much greater extent than did the later. In both series there was a gradual increase in both top and root development comparable with the increase of water supply. No measurements or weights were taken on the root development of the plants, though it was noted that the ratio of roots and crowns to the leaves of plants grown in dry soil was greater than the ratio of roots and crowns to the leaves of plants grown in soil having a high moisture content. There was a progressive increase in the rate of growth of the whole plant with an increase of the water supply.

TABLE 6.—*Effect of soil moisture on the development of the wheat plant in the fall, winter survival, and spring recovery in plantings made in the field but protected from precipitation by a canvas cover.*

| Plat No. | Date of seeding | Approximate moisture content | Fall stand | Spring stand | Spring recovery |
|---|---|---|---|---|---|
| | | % | % | % | |
| 1 | Sept. 30 | 9 | 90 | 90 | Excellent |
| 2 | Sept. 30 | 14 | 95 | 95 | Excellent |
| 3 | Sept. 30 | 21 | 100 | 90 | Good |
| 4 | Sept. 30 | 28 | 100 | 78 | Fair |
| 5 | Sept. 30 | 25 | 95 | 84 | Fair |
| 1 | Oct. 15 | 10 | 90 | 90 | Excellent |
| 2 | Oct. 15 | 15 | 90 | 90 | Excellent |
| 3 | Oct. 15 | 22 | 95 | 90 | Good |
| 4 | Oct. 15 | 28 | 100 | 80 | Poor |
| 5 | Oct. 15 | 25 | 95 | 70 | Poor |

The plants grown with high soil moisture content had very succulent top growth, whereas the plants on the soil with low moisture content took on a decumbent and xerophytic habit of growth.

Chemical analyses for carbohydrates and nitrogenous compounds were not made, hence the actual effect of the various moisture percentages of the soil on the chemical composition of the plant cannot be given. It may be deduced, however, that in the absence of a high percentage of free water the plant underwent a hardening effect. Such hardening effects were obtained by Chandler (8) in experiments on the retention of water from apple tree roots. Salmon and Flemming (29) also noted that cold resistance could be increased in cereals by first slightly wilting the plants. Other investigators,

including Beach and Allen (3), Kiesselbach and Ratcliff (15), Johnson (13, 14), Parker (25), Shutt (30), and Wiegand (32), found that hardiness was associated with a relatively low water content of the tissue.

The effect on the carbohydrate composition of the plant when the water content of the soil is decreased over any considerable period results in a change to a form which has a great water-binding capacity, as noted by Spoehr (31). MacDougal (17) considers this to be the basis of xerophytism. This change in form of carbohydrate materials insures greater imbibitional powers and thereby enables the plant to exist under dry adverse conditions which otherwise would be impossible.

That an actual increase in the pentosans occurs in the wheat plant when grown under very dry conditions was noted by the writer in the fall of 1924. Plants from four dates of seeding were collected from a field having 9% moisture in the upper 6 inches of the soil. These plants were analysed for pentosans, according to the method described in a previous article (12). The results are given in Table 7.

TABLE 7.—*Percentage of pentosans in plants from four dates of seeding; first analysis made when soil contained 9% moisture, second analysis when it contained 26% moisture.*

| Date of analysis | Pentosan content at different dates of seeding | | | | Soil moisture |
|---|---|---|---|---|---|
| | Aug. 22 | Sept. 3 | Sept. 18 | Oct. 3 | |
| | % | % | % | % | % |
| Nov. 6, 1924 | 17.47 | 17.74 | 19.11 | 17.96 | 9 |
| Dec. 5, 1924 | 15.60 | 16.90 | 17.03 | 15.75 | 26 |

It will be noted that there is a higher pentosan content in the plants from all the dates of seeding when plant collections were taken at the time the soil moisture content was low. This percentage decreased after the soil moisture increased, in spite of the fact that the dry matter and the total carbohydrate material increased in the plant as determined by analysis.

Whether or not there was an increase of pentosans in the plants when grown on soil which had a low percentage of moisture content under controlled moisture conditions, and whether this acted as a protection to the plant against cold by retaining the water in the tissues, cannot be stated. It is the belief of the writer, however, that the pentosan substances did increase, but whether this was the only physiological change which occurred due to the differences in water content in the soil, is questionable. Certainly there is considerable field for more definite investigation.

## SUMMARY

1. The percentages of winterkilling of winter wheat plants determined on date of seeding test trials during three consecutive years, 1923 to 1925, inclusive, were found to vary, depending upon the date on which the seed was sown. For a series of seedings made on or close to August 15, August 31, September 21, October 6, and October 19, the percentage of winterhardiness followed in decreasing order the seedings of September 21, September 4, October 3, October 17, and August 15, respectively.

2. The root development of plants for the various dates of seeding is strikingly different. The plants from the first seeding, August 18, show the greatest development of fall root system, followed in order by plants of the second, third, fourth, and fifth seedings. New root development in the spring usually proceeded from the crowns of the plant. The old fall roots as a rule do not continue active growth in the spring, but subsequent spring root development continues from the crown of the plant.

3. Winterkilling did not occur, as a rule, from the fracturing of the roots, but because of the fact that the plants were raised out of the soil. As a result of this raising of the plant, death resulted through desiccation. This is an important factor in the late dates of seeding. If the spring season is humid, the dislodged plants may form new roots and become reestablished in the soil and continue growth.

4. Plants grown in soil, with 10% moisture content lived through the winter better and recovered better in the spring than did plants grown in soil having 25 to 30% moisture content.

5. Grain yields for the three years, 1922 to 1924 inclusive, are directly correlated with the amount of winterkilling. A low percentage stand of plants in the spring and also grain yield are not always indicative of high percentage of winterkilling. Especially is this true for the late seedings, namely, October 5 and October 19. It is on these late seeding dates that the greatest "heaving" of plants results which leads to plant desiccation. Therefore, death of plants in many of these instances is due to spring desiccation and not to actual winterkilling.

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# THE INHERITANCE OF CERTAIN SEED, LEAF, AND FLOWER CHARACTERS IN *GOSSYPIUM HIRSUTUM* AND SOME OF THEIR GENETIC INTERRELATIONS[1]

W. A. CARVER[2]

## INTRODUCTION

A large proportion of the genetic studies in *Gossypium* have been made from crosses between the species *G. hirsutum* and *G. barbadense*. The former species contains most of the American Upland cotton varieties, and the latter contains the Sea Island and Egyptian cottons.

Kearney (1)[3] studied the inheritance of various characters in the $F_2$ of crosses between Upland and Egyptian cotton. As evidence of the wideness of this cross, he cites the great difference in physical characters; the complexity of the $F_2$ segregation; and the frequency of partial and complete sterility. Cook (2) reports similar results. On the other hand, in crosses between Upland and Sea Island cotton, Cook (2) and Webber (3) did not find any very abnormal or sterile plants. From the standpoint of the plant breeder, hybrids between Upland and Sea Island cotton appear to be less discouraging. Meloy and Doyle (4), however, state that,

"Many attempts have been made to combine the superior fiber of Sea Island or Egyptian types of cotton with the desirable cultural characters of the Upland varieties. While crossing is readily accomplished and the results frequently appear promising in the first generation, no hybrid stock has yet been developed that was sufficiently uniform to justify commercial plantings."

Denham (5) found that both *G. hirsutum* and *G. barbadense* have 26 pairs of chromosomes. Hence, the vegetative abnormalities and sterility which occur in $F_2$ and later generations of crosses between the two species evidently result from differences in kind and not in number of chromosomes.

In view of the greater commercial importance of *G. hirsutum* in the United States, and because of the poor promise of species crosses as a basis for plant improvement, the writer has used material from *G. hirsutum* only for the genetic studies reported herein.

## MATERIAL AND METHODS

The writer is indebted to E. F. Grossman of the Florida Experiment Station for furnishing the characters okra leaf, green seed fuzz,

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### FUZZY-TIP SEED

The fuzzy-tip seed is characterized by an entire or partial absence of fuzz except for a tuft of fuzz covering the hilum end of the seed. The fuzzy-tip seed character grades into entire fuzzy in some strains studied, thereby making classification difficult. The strain reported here segregated into fairly distinct classes, fuzzy-tip occurring as a simple Mendelian dominant over entire fuzz.

### GREEN, BROWN, AND WHITE SEED FUZZ

The green-fuzz character used in these studies was brilliantly green, being free from tints of brown or white. The brown-fuzz character was likewise free from any of the common intergrades of color, being intensely brown. The fuzz colors fade rapidly when the seed cotton is exposed to the weather.

Cook (10) crossed Jannovitch Egyptian, having naked seed, by Kekchi, a Guatemalan variety having fuzzy white seed. The $F_1$ generation had green seed fuzz and the $F_2$ segregated to 20 plants with various shades of green fuzz, 5 plants with nearly naked seed, and 5 plants with white seed fuzz. Balls (11) found that in Upland-Egyptian hybrids the presence and absence of seed color form a Mendelian pair, color being dominant. McLendon (6) found fuzz color to be dominant to white in all crosses among Upland varieties and between Upland and Sea Island varieties. Green seed was often found to appear in crosses between apparently white seed.

In the present studies it was found that in *G. hirsutum*, green fuzz is dominant to white fuzz in $F_1$, while in $F_2$ a ratio of 19 green to 6 white was found. Likewise, brown seed fuzz was found to be dominant to white, giving in $F_2$ a ratio of 79 brown seed plants to 24 white seed plants. For the latter ratio, the deviation over the probable error based on a monohybrid segregation is only 1.18.

### BUFF ANTHER

Buff-colored anthers or, to be more exact, buff-colored pollen, can be distinguished easily from its allelomorph, white anthers, when the flower buds are less than half mature.

The writer has not found any report on the inheritance of anther color within the species *G. hirsutum*. Several reports, however, dealing with the inheritance of anther color in crosses between Upland and Egyptian or Sea Island cotton were found. Balls (12) crossed Upland cotton having buff anthers and white petals to Egyptian cotton having both rich yellow anthers and petals. The $F_1$ plants had pale yellow anthers and petals. The $F_2$ and $F_3$ classification was difficult, but the segregation of anther color appeared to

follow the petal color, which segregated in the ratio of 1 yellow: 2 lemon: 1 white. In a later publication, Balls (11) reports that a distinct 1:2:1 ratio of golden yellow, intermediate, and whitish anthers was observed in the second generation of crosses between Upland or Hindi cotton and Egyptian cotton.

McLendon (6) crossed Sea Island cotton having yellow anthers and yellow petals with Upland cotton having buff anthers and white petals. In the $F_1$ generation each pair of characters was intermediate in color. In the $F_2$ generation only the parental combinations appeared, indicating that anther color and petal color are determined by the same factor. The parental forms reappeared in varying proportions in the different crosses. Instead of the expected 3:1 ratio, a ratio of 6.51:1 was found.

Kearney (1) found that in the $F_2$ of Egyptian-Upland hybrids, the factors for petal color and for anther color were completely independent. The very pale pollen of the Upland parent was not recovered in the $F_2$ generation, but by grouping in the dominant class those plants whose pollen equaled or surpassed the intensity of color shown by the $F_1$ and in the recessive class those plants showing less color, a 156:59 ratio was found. The buff anther character reported in the present paper behaved as a simple Mendelian dominant over its allelomorph, white anther. The back cross data given in Table 11 show a ratio of 67 plants having buff anthers to 67 plants having white anthers.

## ENTIRE FUZZY SEED

Thadani (13) found that in *G. hirsutum*, "felted" seed is dominant over "wooly" seed and that "scant fuzz" seed is also dominant over "wooly" seed. The $F_2$ generations of both crosses were too small to show a ratio. The character "wooly" seed is referred to by the present author as fuzzy seed and the characters "scant fuzz" and "felted" are referred to as fuzzy-tip. The term fuzzy-tip is used for this character because in all of the material studied by the writer, the presence of fuzz on the seed tip appeared to be the only invariable distinguishing mark. In naked seed even the tip is entirely free of fuzz. Only when there is fuzz on the seed tip does fuzz appear over the entire seed. From monohybrid "felted-seed" strains, naked seed (naked with the exception of a brush of fuzz) have been isolated. Likewise the reverse has been obtained. These isolations indicate that the tip brush of fuzz is fundamental; and that the presence of fuzz over the seed is controlled by modifying factors. In these studies several fuzzy-tip strains from different sources were used. Only two of the strains, when crossed to fuzzy seed, gave an $F_2$ segregation capable of being accurately grouped into dominant

and recessive classes. Upon self-pollinating plants heterozygous for the fuzz-tip character, a ratio of 20 fuzz-tip to 8 fuzzy-seed was obtained.

### NAKED SEED

Naked seed are, as the name implies, absolutely free of seed covering or fuzz, exposing the hull which is in mature seed a deep black. The percentage of lint associated with naked seed is usually relatively low.

Thadani (13) working with *hirsutum*, found that naked seed was completely dominant over fuzzy seed in the $F_1$ generation. In $F_2$, the segregation was in accord with simple Mendelian inheritance. Dr. R. Y. Winters (unpublished data) of the North Carolina Experiment Station found a simple Mendelian relationship of naked and fuzzy seed in Upland cotton, naked seed being dominant to fuzzy seed. The naked seed character reported in this paper proved to be dominant to fuzzy seed in the $F_1$ generation. An $F_2$ segregation of 605 naked to 216 fuzzy seed was observed, being a 3:1 ratio with a deviation over the probable error of only 1.25.

### GENETIC INTERRELATION BETWEEN THE CHARACTERS

A genetic study of the characters whose interrelations are presented below are being carried through the $F_3$ generation. The results of this study will be published at a later date.

### NAKED SEED CHARACTERS FROM DIFFERENT SOURCES

The five naked-seed strains, pedigree numbers 1 B, 10, 11, 12, and 319, were tested for their genetic identity by intercrossing and observing their $F_2$ segregations. The strains differed decidedly in percentage of lint. It was believed that the differences in lint percentage could be used as a criterion for identifying genetic differences. Table 1 shows the parents used in the different crosses and the $F_1$ and $F_2$ generations. The gene for naked seed in strain 1 B was found to be identical to the genes causing naked seed in 10 and 12; and 12 in like manner was found to be identical to 319 and 11. By deduction, using the time-honored theorem that things equal (or identical) to the same thing are equal (or identical) to each other, it follows that the naked seed character of all five strains is determined by the same gene. The deductions which can be made from each cross are given in the right-hand column of Table 1.

### NAKED AND FUZZY-TIP SEED

In crosses between plants having naked seed and plants having fuzzy-tip seed, the $F_1$ plants had naked seed. The $F_2$ generation segregated in the ratio of 12 naked seed plants: 3 fuzzy-tip seed

TABLE 1.—*Genetic identity tests of different naked-seed strains.*

| Parents and their genotype | $F_1$ generation Naked | $F_1$ generation Fuzzy | $F_2$ generation Naked | $F_2$ generation Fuzzy | Dev./P. E. 15:1 ratio | Established identity |
|---|---|---|---|---|---|---|
| 1 B (10) x 10 (2) | 1 | 0 | 30 | 0 | | The genes for na- |
| N N N N | | | | | 3.98 | ked seed in 1 B and |
| 1 B (1) x 10 (3) | 7 | 0 | 35 | 0 | | 10 are the same. |
| N N N n | | | 9 | 9 | | |
| | | | 44 | 0 | | |
| 1 B (10) x 11 (2) | 4 | 0 | 3 | 0 | | Genes of 1 B and |
| N N N N | | | 7 | 0 | 2.78 | 11 are probably |
| 1 B (5) x 11 (8) | 2 | 0 | 16 | 0 | | identical. |
| N N N N | | | 27 | 0 | | |
| 1 B (11) x 12 (1) | 6 | 0 | 32 | 0 | | Genes of 1 B and |
| N N N N | | | 38 | 0 | 3.36 | 12 are identical. |
| | | | 7 | 0 | | By deduction, 12 = 10. |
| 12 (7) x 319 (2) | 4 | 0 | 22 | 0 | | Genes of 12 and |
| N N N N | | | 54 | 0 | 4.11 | 319 are identical. |
| | | | 39 | 0 | | By deduction, 319 = 1 B = 10 = 12. |
| 12 (4) x 11 (2) | 9 | 0 | 82 | 0 | | Genes of 12 and 11 |
| N N N N | | | 125 | 0 | 6.23 | are identical. Then |
| | | | 58 | 0 | | 1 B = 10 = 11 = 12 = 319. |

plants: 1 fuzzy seed plant. The ratio shows that the gene for naked seed is dominant over the gene for fuzzy-tip seed and that fuzzy seed results from the double recessive condition of the factors for naked and fuzzy-tip seed. The $F_2$ data are arranged in Table 2.

TABLE 2.—*$F_2$ segregation of crosses N N ft ft x n n Ft Ft.*

| Pedigree number | Naked | Fuzzy tip | Fuzzy |
|---|---|---|---|
| 266 (5) | 21 | 8 | 0 |
| (6) | 17 | 9 | 0 |
| (7) | 59 | 9 | 2 |
| (1) | 16 | 7 | 2 |
| 267 (2) | 36 | 14 | 2 |
| (6) | 38 | 11 | 2 |
| 263 (1) | 22 | 8 | 3 |
| (3) | 25 | 5 | 5 |
| Observed | 234 | 71 | 16 |
| Calculated 12:3:1 | 241 | 60 | 20 |

P = 0.22

GREEN, BROWN, AND WHITE SEED FUZZ

The factor for green seed proved to be dominant over the factor for brown seed. An $F_2$ generation of only 13 plants (7 green seed: 6 brown seed) was grown. This number is too small to indicate the

nature of the segregation. However, an $F_3$ progeny test gives more evidence. (See Table 3.) It will be noted that green segregates for brown and that brown segregates for white. Unfortunately, the numbers were not sufficiently large to show the segregation ratio of green and brown. Assuming independent inheritance of the factors for green and brown seed, a ratio of 12 green: 3 brown: 1 white would be expected.

TABLE 3.—*$F_3$ progeny test from the cross br G x Br g.*

| Pedigree number | | $F_2$ phenotype | $F_3$ segregation | | |
|---|---|---|---|---|---|
| | | | Green seed | Brown seed | White seed |
| 312 | (1) | Brown seed | | 22 | 8 |
| | (2) | Brown seed | | 29 | 5 |
| | (3) | Green seed | 3 | 1 | |
| | (4) | Green seed | 1 | 1 | |
| | (5) | Green seed | 2 | | |
| | (6) | Brown seed | | 2 | 1 |
| | (8) | Brown seed | | 7 | |
| | (10) | Green seed | 5 | | |
| | (12) | Green seed | 7 | | |

TABLE 4.—*$F_2$ segregation of crosses r b x R B.*

| Pedigree number | | Red-leaf plants | | Green-leaf plants | |
|---|---|---|---|---|---|
| | | Buff anthers | White anthers | Buff anthers | White anthers |
| 333 | (1) | 7 | 3 | 2 | 0 |
| 261 | (1) | 20 | 6 | 5 | 0 |
| | (3) | 23 | 5 | 5 | 0 |
| | (4) | 29 | 7 | 7 | 0 |
| | (6) | 7 | 5 | 3 | 1 |
| Observed | | 86 | 26 | 22 | 1 |
| Calculated 9:3:3:1 | | 76 | 25 | 25 | 9 |

Deviation ÷ probable error (10:6) = 0.53.

TABLE 5.—*Results of back crosses R B. r b x b b r r.*

| Pedigree numbers | Red-leaf plants | | Green-leaf plants | |
|---|---|---|---|---|
| | Buff anthers | White anthers | Buff anthers | White anthers |
| 261 (4) x 263 (6) | 7 | 2 | 4 | 6 |
| 263 (1) x 261 (4) | 4 | 3 | 3 | 3 |
| 263 (1) x 261 (2) | 0 | 2 | 1 | 2 |
| 263 (7) x 261 (1) | 8 | 4 | 2 | 6 |
| 263 (7) x 261 (?) | 7 | 5 | 2 | 3 |
| 261 (6) x 266 (5) | 1 | 4 | 2 | 4 |
| 266 (6) x 261 (4) | 4 | 9 | 2 | 2 |
| 266 (4) x 261 (4) | 6 | 1 | 2 | 2 |
| 266 (3) x 261 (4) | 3 | 10 | 4 | 6 |
| 266 (7) x 261 (4) | 7 | 7 | 4 | 5 |
| Observed | 47 | 47 | 26 | 39 |
| Calculated 1:1:1:1 | 39.8 | 39.8 | 39.7 | 39.7 |

Deviation ÷ probable error (1:1) = 1.53.

### RED LEAF AND BUFF ANTHER

The characters red leaf and buff anther proved to be independent in inheritance, as shown by $F_2$ segregations (Table 4) and by back crosses (Table 5). The deviation over the probable error of the 10:6 ratio in Table 4 is only 0.53 and only 1.53 in Table 5 based on a 1:1 ratio secured by grouping the parental combinations in the one class and the new combinations in the other.

### RED LEAF AND PETAL SPOT

Red leaf and petal spot[5] are genetically independent as shown by an $F_2$ segregation (Table 6) and by back cross data (Table 7), since the deviation over the probable error for the two sets of data are only 1.1 and 0.48, respectively.

TABLE 6.—*$F_2$ summary of crosses r s x R S.*

| Pedigree number | Red-leaf plants | | Green-leaf plants | |
|---|---|---|---|---|
| | Petal spot | No spot | Petal spot | No spot |
| 261 (1) | 22 | 4 | 4 | 1 |
| (3) | 19 | 9 | 5 | 0 |
| (4) | 28 | 10 | 5 | 2 |
| (6) | 8 | 4 | 3 | 1 |
| 324 (1) | 27 | 18 | 9 | 2 |
| 333 (1) | 6 | 4 | 2 | 0 |
| Observed | 110 | 49 | 28 | 6 |
| Calculated | | | | |
| 9:3:3:1 | 109 | 36 | 36 | 12 |

Deviation ÷ probable error (10:6) = 1.1.

TABLE 7.—*Results of back crosses R S. r s x r r s s.*

| Pedigree numbers | Red-leaf plants | | Green-leaf plants | |
|---|---|---|---|---|
| | Petal spot | No spot | Petal spot | No spot |
| 261 (4) x 263 (6) | 2 | 7 | 4 | 5 |
| 263 (1) x 261 (4) | 3 | 4 | 4 | 1 |
| 263 (1) x 261 (2) | 1 | 1 | 2 | 1 |
| 263 (7) x 261 (1) | 6 | 6 | 4 | 3 |
| 263 (7) x 261 (?) | 5 | 5 | 3 | 2 |
| 261 (6) x 266 (5) | 3 | 2 | 3 | 3 |
| 266 (6) x 261 (4) | 5 | 7 | 2 | 2 |
| 266 (4) x 261 (4) | 2 | 5 | 1 | 3 |
| 266 (3) x 261 (4) | 4 | 6 | 3 | 7 |
| 266 (7) x 261 (4) | 9 | 5 | 3 | 6 |
| Observed | 40 | 48 | 29 | 33 |
| Calculated | | | | |
| 1:1:1:1 | 37.5 | 37.5 | 37.5 | 37.5 |

Deviation ÷ probable error (1:1) = 0.48.

[5] HARLAND, S. C. The genetics of cotton, Part I. The inheritance of petal spot in New World cottons. Jour. Genetics, 20:365–385. 1929. Harland studied the inheritance of the factors R, S, and Y (yellow corolla) in inter-species crosses. He concludes that there are two factors for petal spot, one being linked to Y and one independent of Y; that one of these factors for petal spot is linked to R; and that Y and R are independent—to be shown in a later paper. The R factor has not been tested with the factor S which is linked to Y.

### RED LEAF AND OKRA LEAF

McLendon (6) reported the results of crossing the characters red leaf and okra leaf. His $F_2$ data are as follows: red leaf—okra leaf, 258; red leaf—normal leaf, 81; green leaf—okra leaf, 111; green leaf—normal leaf, 38. The deviation from a 10:6 ratio is $9 \pm 7.21$.

The present paper gives additional data on the genetic interrelation of red leaf and okra leaf. Table 8 gives an $F_2$ segregation of the two characters. The deviation over the probable error is a little large, 2.44. The deviation, however, is caused by a deficiency of plants in the mean $F_2$ classes. If there were linkage between the factors for red leaf and okra leaf, an excess of plants would be expected to occur in the mean classes. The deviation then was evidently due to random sampling. The data given here, together with the data presented by McLendon, indicate very strongly that the factors *R* and *O* are inherited independently.

TABLE 8.—*$F_2$ segregation of crosses r O x R o.*

| Pedigree number | Red-leaf plants: Okra leaf | Red-leaf plants: Normal leaf | Green-leaf plants: Okra leaf | Green-leaf plants: Normal leaf |
|---|---|---|---|---|
| 333 (1) | 9 | 1 | 1 | 1 |
| 261 (1) | 23 | 3 | 5 | 0 |
| (6) | 7 | 5 | 3 | 1 |
| 323 (3) | 9 | 2 | 1 | 1 |
| 324 (1) | 35 | 10 | 8 | 3 |
| Observed | 83 | 21 | 18 | 6 |
| Calculated 9:3:3:1 | 72 | 24 | 24 | 8 |

Deviation ÷ probable error (10:6) = 2.44.

### RED LEAF AND NAKED SEED

In the second generation of the cross between red leaf-fuzzy seed and green leaf-naked seed, the characters were found to segregate independently, the deviation from a 10:6 ratio being only $2 \pm 3.64$. The data are arranged in Table 9.

TABLE 9.—*$F_2$ segregation of cross r N x R n.*

| Pedigree number | Red-leaf plants: Naked seed | Red-leaf plants: Fuzzy seed | Green-leaf plants: Naked seed | Green-leaf plants: Fuzzy seed |
|---|---|---|---|---|
| 371 (3) | 18 | 8 | 3 | 3 |
| (7) | 13 | 5 | 6 | 1 |
| (10) | 17 | 6 | 9 | 3 |
| (11) | 20 | 1 | 6 | 5 |
| Observed | 68 | 20 | 24 | 12 |
| Calculated 9:3:3:1 | 70 | 23 | 23 | 8 |

Deviation ÷ probable error (10:6) = 0.55.

### BUFF ANTHER AND PETAL SPOT

The genetic interrelation of buff anther and petal spot was tested by means of an $F_2$ and back cross generation. (See Tables 10 and 11.)

The agreement of the observed ratios with the calculated, assuming independent inheritance between the factors B and S, is very close. The deviation over the probable error for the 10:6 ratio of the $F_2$ segregation and for a 1:1 ratio of the back cross is only 0.75 and 0.51, respectively.

TABLE 10.—*$F_2$ segregation of crosses b s x B S.*

| Pedigree number | Buff anthers | | White anthers | |
|---|---|---|---|---|
| | Petal spot | No spot | Petal spot | No spot |
| 261 (1) | 21 | 4 | 5 | 1 |
| (3) | 21 | 7 | 3 | 2 |
| (4) | 26 | 10 | 7 | 2 |
| 333 (1) | 6 | 3 | 2 | 1 |
| 359 (1) | 15 | 7 | 5 | 1 |
| Observed | 89 | 31 | 22 | 7 |
| Calculated | | | | |
| 9:3:3:1 | 84 | 28 | 28 | 9 |

Deviation ÷ probable error (10:6) = 0.75.

TABLE 11.—*Results of back crosses B S. b s x bb ss.*

| Pedigree numbers | Buff anthers | | White anthers | |
|---|---|---|---|---|
| | Petal spot | No spot | Petal spot | No spot |
| 261 (4) x 263 (6) | 3 | 7 | 3 | 5 |
| 263 (1) x 261 (4) | 3 | 4 | 4 | 1 |
| 263 (1) x 261 (2) | 1 | 0 | 2 | 2 |
| 263 (7) x 261 (1) | 4 | 5 | 6 | 4 |
| 263 (7) x 261 (?) | 6 | 2 | 3 | 4 |
| 261 (6) x 266 (5) | 2 | 4 | 1 | 4 |
| 266 (6) x 261 (4) | 1 | 7 | 2 | 1 |
| 266 (3) x 261 (4) | 2 | 5 | 5 | 8 |
| 266 (7) x 261 (4) | 7 | 4 | 5 | 7 |
| Observed | 29 | 38 | 31 | 36 |
| Calculated | | | | |
| 1:1:1:1 | 33.5 | 33.5 | 33.5 | 33.5 |

Deviation ÷ probable error (1:1) = 0.51.

### BUFF ANTHER AND OKRA LEAF

A dihybrid segregation of buff anther and okra leaf is given in Table 12. The agreement of the observed and calculated ratios is not very close, the deviation divided by the probable error being 2.2.

TABLE 12.—*$F_2$ segregation of crosses b O x B o*

| Pedigree number | Buff anthers | | White anthers | |
|---|---|---|---|---|
| | Okra leaf | Normal leaf | Okra leaf | Normal leaf |
| 261 (i) | 22 | 3 | 6 | 0 |
| (3) | 21 | 7 | 4 | 1 |
| (4) | 29 | 7 | 6 | 3 |
| (6) | 7 | 3 | 4 | 2 |
| 323 (4) | 13 | 3 | 4 | 0 |
| 333 (1) | 8 | 1 | 2 | 1 |
| Observed | 100 | 24 | 26 | 7 |
| Calculated | | | | |
| 9:3:3:1 | 88 | 29.5 | 29.5 | 10 |

An excess of plants, however, occur in the extreme classes which does not suggest linkage.

### BUFF ANTHER AND NAKED SEED

Buff anther and naked seed were found to segregate independently in the $F_2$ generation of the cross b N by B n. The data are arranged in Table 13.

TABLE 13.—*$F_2$ segregation of crosses b N x B n.*

| Pedigree number | Buff anthers | | White anthers | |
|---|---|---|---|---|
| | Naked seed | Fuzzy seed | Naked seed | Fuzzy seed |
| 371 (10) | 21 | 6 | 5 | 3 |
| 976 (3) | 17 | 5 | 7 | 5 |
| (4) | 15 | 6 | 4 | 2 |
| 977 (5) | 12 | 2 | 5 | 1 |
| (7) | 12 | 3 | 5 | 2 |
| Observed | 77 | 22 | 26 | 13 |
| Calculated 9:3:3:1 | 78 | 26 | 26 | 8 |

Deviation ÷ probable error (10:6) = 1.04.

### PETAL SPOT AND OKRA LEAF

As shown in Table 14, the factors for petal spot and okra leaf segregated independently in the $F_2$ generation involving the two factors, the deviation over the probable error for a 10:6 ratio being only 0.21.

TABLE 14.—*$F_2$ segregation of crosses s O x S o.*

| Pedigree number | Petal spot | | No spot | |
|---|---|---|---|---|
| | Okra leaf | Normal leaf | Okra leaf | Normal leaf |
| 261 (1) | 22 | 4 | 5 | 0 |
| (3) | 18 | 6 | 7 | 2 |
| (4) | 25 | 8 | 10 | 2 |
| (6) | 7 | 5 | 3 | 1 |
| 323 (9) | 16 | 5 | 4 | 4 |
| 324 (1) | 29 | 7 | 14 | 6 |
| 333 (1) | 7 | 1 | 3 | 1 |
| Observed | 124 | 36 | 46 | 16 |
| Calculated 9:3:3:1 | 125 | 41.5 | 41.5 | 14 |

Deviation ÷ probable error (10:6) = 0.21.

TABLE 15.—*$F_2$ segregation of crosses s N x S n.*

| Pedigree number | Petal spot | | No spot | |
|---|---|---|---|---|
| | Naked seed | Fuzzy seed | Naked seed | Fuzzy seed |
| 371 (10) | 16 | 2 | 7 | 7 |
| 977 (5) | 15 | 2 | 2 | 1 |
| (7) | 12 | 4 | 3 | 1 |
| (11) | 26 | 6 | 8 | 1 |
| Observed | 69 | 14 | 20 | 10 |
| Calculated 9:3:3:1 | 64 | 21 | 21 | 7 |

Deviation ÷ probable error (10:6) = 2.31.

PETAL SPOT AND NAKED SEED

An $F_2$ segregation which shows the genetic interrelation of the factors S and N is given in Table 15. The deviation from a 10:6 ratio is $8 \pm 3.46$. The deviation, though large, does not indicate linkage since the nonparental classes contain an excess of plants. Hence, the likelihood that S and N are linked is small.

NAKED SEED AND OKRA LEAF

Evidence that the factors for naked seed and okra leaf are independent in inheritance is furnished by the $F_2$ data given in Table 16. The agreement of the observed numbers with the calculated based on a 10:6 ratio is very good, the deviation over the probable error being only 1.0.

TABLE 16.—*$F_2$ segregation of crosses n O x N o.*

| Pedigree number | Naked seed | | Fuzzy seed | |
|---|---|---|---|---|
| | Okra leaf | Normal leaf | Okra leaf | Normal leaf |
| 344 (1) | 44 | 13 | 15 | 4 |
| (4) | 22 | 5 | 8 | 2 |
| (8) | 28 | 7 | 9 | 5 |
| (13) | 51 | 8 | 18 | 4 |
| 266 (1) | 12 | 4 | 8 | 1 |
| (5) | 15 | 6 | 5 | 3 |
| (6) | 10 | 7 | 6 | 3 |
| (7) | 38 | 21 | 7 | 4 |
| 267 (2) | 22 | 14 | 9 | 7 |
| (6) | 28 | 10 | 11 | 2 |
| 268 (3) | 17 | 7 | 5 | 1 |
| 263 (1) | 17 | 5 | 9 | 2 |
| (3) | 19 | 6 | 8 | 2 |
| Observed | 323 | 113 | 118 | 40 |
| Calculated 9:3:3:1 | 334 | 111.5 | 111.5 | 37 |

Deviation ÷ probable error (10:6) = 1.0.

SUMMARY

In a study of inheritance in *G. hirsutum*, no sterility, abnormal characters, or non-Mendelian segregations were observed in the $F_1$ and $F_2$ generations of crosses between standard and unimproved varieties. This is in contrast to the findings of several workers who made studies of the inheritance in crosses between *G. hirsutum* and *G. barbadense*.

The characters naked seed and fuzzy-tip seed proved to be simple Mendelian dominants to entire fuzzy seed.

Five naked seed characters, having lint percentages varying from about 30 to practically no lint, proved to be genetically identical with regard to the absence of seed fuzz.

Naked seed was found to be dominant in $F_1$ to fuzzy-tip seed and to segregate in $F_2$ in the ratio of 12 naked: 3 fuzzy-tip: 1 fuzzy.

Green seed fuzz and brown seed fuzz proved to be dominant to white seed fuzz, each cross giving a simple monohybrid segregation in $F_2$. Green seed, in turn, proved dominant to brown. The numbers in $F_2$ and $F_3$ were too small to demonstrate a complete dihybrid segregation, but assuming independent inheritance of the factors for green and brown seed a ratio of 12 green: 3 brown: 1 white would be expected.

Using the characters red leaf, petal spot, naked seed, buff anthers, and okra leaf, all the possible crosses were made. No indication of linkage was evident between any of the characters in the $F_2$ generations. In addition to their $F_2$ segregations, the factors *R* and *B*, *R* and *S*, and *B* and *S* were tested by means of back crosses.

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# VARIETAL AND SEASONAL VARIATION OF "MOTES" IN UPLAND COTTON[1]

H. E. REA[2]

## INTRODUCTION

In the production of sound seed the cotton plant is very often wasteful. Many of the potential seeds or ovules produced in the cotton blossoms are aborted and result in "motes" instead of sound seed. These motes fail to produce any fibers of commercial value and very probably detract from the productivity of the plant. Apparently a method of preventing this waste in production would be highly desirable and conducive to greater yields of lint. A satisfactory method of avoiding this type of waste will probably come only after more complete knowledge is available of the factors associated with the occurrence of motes. An earlier paper[3] describes the loci in the lock where the motes most frequently occur. The location of the motes suggested some rather interesting hypotheses as to their cause. No doubt a knowledge of the varietal and seasonal variation in the production of motes might develop additional information as to their probable cause as well as help in evolving a method of their elimination.

The object of this second study was to determine the varietal and seasonal variations in the occurrences of motes in the more important commercial varieties of cotton grown in the blackland area of Texas. The percentage of motes of all the varieties grown in the regular cotton variety test at Substation No. 5, Temple, Texas, was determined for the years 1925 and 1926. Sixteen varieties were included in this test which covers the range of varieties ordinarily used by the planters of Texas. The wide range of varieties should facilitate their classification into hereditary groups. Fortunately, the two years included in this study were contrasting as to climatic conditions and furnish data as to the influence of some of the environmental factors on motes.

## METHOD USED

For each variety tested, approximately 50 individual stalks were studied each year. The plants were harvested when the cotton was about 75% open and all observations were based on the open boll

[1]Contribution from the Division of Agronomy, Texas Agricultural Experiment Station. Received for publication January 12, 1929.

[2]Agronomist, Sub-station No. 5, Temple, Texas.

[3]REA, H. E. Location of motes in the Upland cotton lock. Jour. Amer. Soc. Agron., 20:1064–1068. 1928.

of the individual plants. The stalks were taken as they stood in the row to insure random sampling and the plants of all varieties of a given year were harvested on the same day so that the observations made on the various varieties were comparable. In order to avoid any error in counting the number of motes, the cotton was harvested in the burr and the counts made as each lock was pulled from the burr. The total number of sound seed plus the total number of motes in the open boll was used as the total number of ovules formed for these bolls. The records on motes were expressed as the percentage of motes to the total number of ovules.

The cotton used to secure data on motes in 1925 was produced in a very dry year on Lewisville clay soil, while in 1926 it was grown on Trinity clay soil during a favorable season of high rainfall. The total rainfall for 1925 was 22.67 inches compared to 41.11 inches for 1926 and 36.32 inches for the 14-year mean, including both of these years.[4] The rainfall and humidity during the blossoming season of cotton shows the same general contrast as the annual precipitation.

## EXPERIMENTAL RESULTS

### VARIETAL DIFFERENCES

The mean percentage of motes for each variety studied in 1925 is presented in Table 1. In securing the averages, 759 plants were examined and these individual plants showed a range from no motes to as high as 60%. The range of the mean percentage of the several

TABLE 1.—*Mean percentage of motes in cotton varieties, 1925.*

| No. | Variety | Mean percentage motes | Differs significantly from |
|---|---|---|---|
| 1 | Anton | 22.3 ± 1.02 | 10, 12, 13, 14, 15, 16 |
| 2 | Kasch | 23.2 ± .77 | 10, 12, 13, 14, 15, 16 |
| 3 | Harper | 23.4 ± .89 | 12, 13, 14, 15, 16 |
| 4 | Belton | 23.4 ± .83 | 12, 13, 14, 15, 16 |
| 5 | Cliett's Superior | 23.9 ± .79 | 13, 14, 15, 16 |
| 6 | Mebane | 26.0 ± .62 | 16 |
| 7 | Rowden | 26.2 ± 1.26 | 16 |
| 8 | Qualla | 26.2 ± 1.19 | 16 |
| 9 | Truitt | 27.0 ± 1.12 | 16 |
| 10 | Snowflake | 28.1 ± .88 | 1, 2, 16 |
| 11 | Sunshine | 28.3 ± 1.18 | 16 |
| 12 | Lonestar | 28.7 ± .94 | 1, 2, 3, 4, 16 |
| 13 | Lankart | 29.5 ± 1.01 | 1, 2, 3, 4, 5, 16 |
| 14 | New Boykin | 29.6 ± 1.03 | 1, 2, 3, 4, 5, 16 |
| 15 | Acala | 29.6 ± .71 | 1, 2, 3, 4, 5, 16 |
| 16 | Durango | 47.4 ± .78 | All other varieties |

[4]REA, H. E. Variability in staple length of some commercial varieties of cotton. Jour. Amer. Soc. Agron., 20:703–709. 1928.

varieties varied from 22.3 to 47.4 The significance of the mean difference between each variety and every other variety was determined to discover the varietal difference that existed. The results of these comparisons are included in Table 1.

TABLE 2.—*Mean percentage of motes in cotton varieties, 1926.*

| No. | Variety | Mean percentage motes | Differs significantly from |
|---|---|---|---|
| 1 | Sunshine | 14.7 ± .46 | All except Rowden |
| 2 | Belton | 17.9 ± .54 | 1, 13, 14, 15, 16 |
| 3 | Rowden | 18.1 ± .81 | 14, 15, 16 |
| 4 | Truitt | 18.3 ± .68 | 1, 14, 15, 16 |
| 5 | New Boykin | 18.4 ± .79 | 1, 15, 16 |
| 6 | Kasch | 18.5 ± .73 | 1, 15, 16 |
| 7 | Qualla | 18.8 ± .74 | 1, 16 |
| 8 | Harper | 19.2 ± .73 | 1, 16 |
| 9 | Lankart | 20.1 ± .60 | 1, 16 |
| 10 | Lonestar | 20.3 ± .58 | 1, 16 |
| 11 | Anton | 20.6 ± .62 | 1 |
| 12 | Cliett's Superior | 20.7 ± .62 | 1 |
| 13 | Acala | 21.6 ± .67 | 1, 2 |
| 14 | Mebane | 22.7 ± .65 | 1, 2, 3, 4 |
| 15 | Durango | 23.6 ± .71 | 1, 2, 3, 4, 5, 6 |
| 16 | Snowflake | 23.9 ± .61 | 1, 2, 3, 4, 5, 6, 7, 8, 9, 10 |

In studying the varietal comparisons for 1925, Durango produced the highest mean percentage of motes and was significantly higher than all other varieties. Several varieties were intermediate in the production of motes and differed only from Durango. These intermediate varieties were Mebane, Rowden, Qualla, Truitt, and Sunshine. All the other varieties were distinguished by their significant difference from additional varieties and for convenience of discussion were designated as low or high varieties. Anton, Kasch, Harper, Belton, and Cliett's Superior were classified as low producers of motes. All these varieties were significantly lower than Lankart, New Boykin, and Acala. The four lowest members of this class, *viz.*, Anton, Kasch, Harper, and Belton, were lower than Lonestar; while Anton and Kasch were also lower than Snowflake. The high-producing varieties were Snowflake, Lonestar, Lankart, New Boykin, and Acala. These varieties were all significantly higher than Anton and Kasch. Except for Snowflake, these were also higher than Harper and Belton. The three highest varieties, Lankart, New Boykin, and Acala, were higher than Cliett's Superior in addition to the varieties already designated.

Table 2 gives the mean percentage of motes for the varieties used in 1926. A total of 564 plants were studied in that year and all of the

plants produced some motes. The range for the individual plants was from 1 to 45% of motes. The range of the mean percentage for the several varieties was from 14.7 to 23.9. Again each variety was compared to each of the others and the same method of tabulating used as in the 1925 varieties.

Sunshine was the outstanding variety in 1926. Sunshine was as distinctive for its low percentage of motes in 1926 as Durango for its high percentage in 1925. Except for Rowden, Sunshine was significantly lower than all other varieties in 1926. It was not significantly lower than Rowden because of Rowden's high probable error. Compared to Sunshine, the intermediate varieties were Anton and Cliett's Superior. These two were significantly different only from Sunshine. The remaining varieties studied in their relation to varieties other than Sunshine exhibited several distinctions and can best be discussed by arranging them into a low percentage and a high percentage class. Belton, Truitt, New Boykin, Kasch, Qualla, Harper, Lankart, and Lonestar were characterised by low percentages. This list of varieties was significantly lower than Snowflake. The four lowest varieties were lower than Durango and Snowflake, while Truitt and Belton were also lower than Mebane. Belton was the only variety significantly lower than Acala. The high percentage varieties were Acala, Mebane, Durango, and Snowflake. All were higher than Belton, while Mebane, Durango, and Snowflake were higher than Rowden, Truitt, and New Boykin. Two of these varieties, Durango and Snowflake, were higher than Kasch, while Snowflake was also higher than Qualla, Harper, Lankart, and Lonestar.

From a consideration of Tables 1 and 2, it will be found that 69 and 50 of the comparisons made for 1925 and 1926, respectively, were significant. A total of 240 comparisons were made and the fact that less than half of these were significant indicates that many individual varieties were not distinctly different from each other.

An accurate classification of every variety could not be made from the limited data available, but the results of the two years studied exhibited abundant evidence of varietal differences in the production of motes. The highest and lowest varieties were easily distinguished. Belton, Kasch, and Harper were consistently low producers of motes, while Acala, Snowflake, and Durango were consistently high producers. Many of the varieties were not very consistent and did not react uniformly to the different sets of environmental factors. Anton, Cliett's Superior, Rowden, Sunshine, Truitt, and Qualla varied from intermediate to low varieties from season to season. Mebane, Lankart, Lonestar, and New Boykin showed variation from relatively

high to low percentages of motes for the years studied. Outstanding among these inconsistent varieties were Sunshine and Anton. These varieties completely changed rank from one season to the other.

## SEASONAL DIFFERENCES

The total rainfall for 1925 was 22.87 inches and the mean percentage of motes was 27.8 ± .28. The rainfall for 1926 was 41.11 inches, while the percentage of motes was 19.8 ± .18. The percentage of motes for the dry year was significantly higher than for the wet year. Table 3 presents the difference between the 1925 and the 1926 varieties. It will be seen from this table that there was a significant difference in favor of a high percentage of motes for 1925 in 12 of the varieties. Qualla, Mebane, Cliett's Superior, and Harper fail to show a significant difference between the two years. These latter varieties are all of the Mebane type.

TABLE 3.—*Mean percentage of motes in cotton varieties, 1925–1926.*

| Variety | Mean percentage of motes 1925 | 1926 | Difference |
|---|---|---|---|
| Truitt | 27.0 ± 1.12 | 18.3 ± .68 | 9.7 ± 1.31 |
| Qualla | 26.2 ± 1.19 | 18.8 ± .74 | 7.4 ± 1.40 |
| Anton | 22.3 ± 1.02 | 20.6 ± .62 | 1.7 ± 1.19 |
| Mebane | 26.0 ± .62 | 22.7 ± .65 | 3.3 ± .90 |
| Kasch | 23.2 ± .77 | 18.5 ± .73 | 4.7 ± 1.06 |
| Sunshine | 28.3 ± 1.18 | 14.7 ± .40 | 13.6 ± 1.25 |
| Cliett's Superior | 23.9 ± .79 | 20.7 ± .62 | 3.2 ± 1.00 |
| New Boykin | 29.6 ± 1.03 | 18.4 ± .79 | 11.2 ± 1.30 |
| Lonestar | 28.7 ± .94 | 20.3 ± .58 | 8.4 ± 1.10 |
| Acala | 29.6 ± .71 | 21.6 ± .67 | 8.0 ± .98 |
| Durango | 47.4 ± .78 | 23.6 ± .71 | 23.8 ± 1.05 |
| Harper | 23.4 ± .89 | 19.2 ± .73 | 4.2 ± 1.15 |
| Belton | 23.4 ± .83 | 17.9 ± .54 | 5.5 ± .99 |
| Snowflake | 28.1 ± .88 | 23.9 ± .61 | 4.2 ± 1.07 |
| Rowden | 26.2 ± 1.26 | 18.1 ± .81 | 8.1 ± 1.50 |
| Lankart | 29.5 ± 1.01 | 20.1 ± .60 | 9.4 ± 1.14 |
| All varieties | 27.8 ± .28 | 19.8 ± .18 | 8.0 ± .33 |

Kearney[5] has reported considerable variation from year to year in mean number of sound seed per boll as percentage of the mean number of ovules for bolls of Pima cotton produced from naturally pollinated flowers at Sacaton, Arizona. The figures reported by Kearney show a variation of from 67 to 89% sound seed over a seven-year period. These figures should be complementary to the percentage of motes so that they would represent a variation of from 33 to 11%

[5]KEARNEY, T. H. Self-fertilization and cross-fertilization in Pima cotton. U. S. D. A. Bul. 1134. 1923.

of motes for the year covered. Environmental factors were, no doubt, largely responsible for these fluctuations since the same variety of cotton was used. It was not apparent what particular environmental factors were responsible for the variation observed by Kearney. However, he specifically accounted for a similar variation between fields for the same season by the difference in insect population.

As suggested in an earlier paper it is not likely that the motes are the result of any one cause. Apparently, motes might be caused by moisture or nutritional deficiencies or they might be caused by imperfect fertilization. Dry climatic conditions would be expected to affect directly the completeness of fertilization. It is quite likely that receptiveness of the stigma of the cotton blossom, and therefore the subsequent vitality of the pollen tube, might easily be depreciated by a low atmospheric humidity. There is a possibility, of course, of seed being aborted shortly after fertilization is complete in case of deficiency of moisture. To say the least, extreme drought conditions are very conducive to the production of a large number of motes.

## CONCLUSIONS

The results of the study on the percentage of the motes made in the 16 varieties grown in 1925 and 1926 justify the following conclusions:

1. The occurrence of motes in the commercial varieties of cotton studied was very common. In a study embracing two years, 1,323 plants were examined and only 2 failed to have any motes.

2. The percentage of motes occurring in the commercial varieties of cotton studied showed a wide range. The range exhibited was from 14.7% for Sunshine in 1926 to 47.4% for Durango in 1925. Durango showed the highest percentage of motes and Anton the lowest in 1925; Snowflake the highest and Sunshine the lowest in 1926.

3. Distinct differences exist between varieties as to the production of motes, regardless of season. Durango was significantly higher than most other varieties for both years. Acala, Snowflake, and Durango exhibited a marked contrast to Belton, Kasch, and Harper.

4. Seasonal conditions account for a great variation in the percentage of motes produced. The first year covered by this study, 1925, was much drier than the second year, 1926. Seventy-five per cent of the varieties studied showed significantly higher percentages of motes in 1925 than in 1926.

# A COMPOSITE HYBRID MIXTURE[1]

HARRY V. HARLAN AND MARY L. MARTINI[2]

Composite hybrid mixtures are not new. The senior author has grown one such for many years and numerous breeders have grown bulk lots of one or more crosses to allow segregation and stabilization to take place. This method of handling hybrids probably secures as valuable segregates as any other and is economical of space and effort. At present we are trying to make a wider adaptation of the scheme in barley than has been attempted before. We have good varieties and varieties that are almost good. The full utilization of the latter constitutes a real problem. At all experiment stations there are varieties which have been tested for many years. They are too good to throw away and not good enough to distribute. Such barleys must have some inherent quality that causes them to be of perennial promise. Whatever this intangible quality may be, it quite probably is not identical in the different sorts. If it is not identical, hybridization should allow a recombination of characters in such a way as to produce superior types. From the mass of material available it is impossible to select the most probable parents for producing the desired superior sorts. The originator of Marquis wheat could hardly have known that the two parents chosen held the possibility of producing that variety. If one were to take all the possible parents, the volume of work would become prohibitive.

The same argument is true of our leading sorts. They are good. They are the best we have. Their hybrids might contain progenies of even greater value than the best of the parents. Not all varieties can be used in this way, as the labor involved in utilizing a limited number is very great. In the 20 years that the senior author has been connected with the barley investigations of the United States Department of Agriculture some 5,000 barleys have been grown. Most of these have come from foreign sources. They have included sorts from every barley-growing region of the world. Most of the 5,000 were discarded after a preliminary test had shown them to be obviously without value.

From this large volume of material it was finally decided to select a number of varieties, including both superior and promising sorts which were outstanding for some quality or other, and to intercross

[1]Contribution from the Office of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture, Washington, D. C. Received for publication January 17, 1929.

[2]Principal Agronomist in Charge, Barley Investigations, and Assistant Botanist, Barley Investigations, respectively.

these among themselves. (See Table 1.) It also was decided to choose these barleys from the various barley-growing regions of the world in such a way as to cover the range of ecological races so far as possible. From Egypt, for instance, were selected those types which had shown the highest promise in the United States. The same was done for India, Manchuria, North Europe, and Algeria.

TABLE 1.—*Origin and description of varieties used in composite cross.*

| Name | C. I. No. | Origin | Fertility | Awns | Color | Remarks |
|---|---|---|---|---|---|---|
| Horn | 926 | North Europe | 2 | rough | white | |
| Hannchen | 531 | North Europe | 2 | rough | white | |
| Wisconsin Winter | 2159 | Southeast Europe | 6 | rough | white | |
| Orel | 351 | Russia | 2 | rough | white | |
| Arequipa | 1256 | Northwest Africa | 6 | rough | white | |
| Algerian | 1179 | Northwest Africa | 6 | rough | white | |
| Lion | 923 | Northwest Africa | 6 | smooth | black | |
| Atlas | 4118 | Northwest Africa | 6 | rough | white | |
| Sandrel | 937 | Northwest Africa | 6 | rough | white | |
| Maison Carrée | 3387 | Northwest Africa | 6 | rough | white | |
| Club Mariout | 261 | Egypt | 6 | rough | white | |
| California Mariout | 3625 | Egypt | 6 | rough | white | |
| Good Delta | 3801 | Egypt | 6 | rough | white | |
| Minia | 3556 | Egypt | 6 | rough | white | |
| White Smyrna | 910 | East Mediterranean | 2 | rough | white | |
| Palmella Blue | 3609 | East Mediterranean | 2 | rough | white | |
| Trebi | 936 | Armenia | 6 | rough | white | |
| Multan | 3401 | India | 6 | rough | white | |
| Lyallpur | 3403 | India | 6 | rough | white | |
| Everest | 4105 | Mt. Everest | 6 | rough | white | naked |
| Manchuria | 2330 | Manchuria | 6 | rough | white | |
| Oderbrucker | 4666 | Eurasian Plain | 6 | rough | white | |
| Han River | 206 | China | 6 | rough | white | |
| Flynn | 1311 | Hybrid | 6 | rough | white | |
| Glabron | 4577 | Hybrid | 6 | smooth | white | |
| Alpha | 959 | Hybrid | 2 | rough | white | |
| Golden Pheasant | 2488 | Hybrid | 2 | rough | white | |
| Meloy | 1176 | Hybrid | 6 | hooded | white | |

When completed, the list comprised 28 varieties. The possible number of crosses between 28 varieties is 378. Since the handling of this number of crosses individually is burdensome, it is planned to mix equivalent quantities of the $F_2$ seed from each cross and to grow this mixture in plats at as many stations as desire to make use of the material. After a few years these plats should contain a large number of strains homozygous for most factors and natural selection should have eliminated a great many of the weaker combinations. At the end of five years head selections may be made with reasonable hope of isolating some very desirable varieties.

Nearly all the 378 hybrids have been made and the $F_2$ generation will be harvested this year. In one of the varieties the series is not complete. Single heads were used for seeding the parent rows for hybridization. In Orel, by chance, the spike chosen was not typical of the variety and the error was discovered so late that the combinations with proper varieties were obtained only in part.

Among the 28 varieties three two-rowed sorts from North Europe were included. These were Golden Pheasant, a rather striking hybrid semi-winter variety recently introduced from Scotland; Horn, which has produced high yields in Montana; and Hannchen, one of the Svalöf barleys, which has been widely tested for a good many years. From southeastern Europe we included Wisconsin Winter, a variety which has shown promise in the winter section of the southeastern United States. Russia is represented by only one variety, Orel, a two-rowed sort introduced from near the town of that name. Orel has produced high yields as a winter variety at Arlington Experiment Farm, Rosslyn, Virginia, and as a spring variety at Akron, Colorado, and Aberdeen, Idaho.

Many good varieties have been secured from northwest Africa and six of these were included among the parents. Arequipa is a stiff-strawed Coast type and Atlas is a selection of Coast as now grown on the Pacific slope. Maison Carrée was originally selected by Professor Ducellier in Algeria and looks promising in this country. Algerian is a late variety of the Coast type. Sandrel has been tested in nurseries and plats at many experiment stations and has always been among the higher yielding sorts. Lion is the basis of all the smooth-awned hybrids found at American experiment stations. The Egyptian barleys have shown great promise in the western part of the United States. Four six-rowed sorts were included in the list of parents. Three of these, Club Mariout, Good Delta, and Minia, came from the irrigated lands along the Nile. The first two of these three were secured from lands irrigated from canals, but the third,

Minia, was selected from a field of barley in one of the basins west of the Nile where the barley lands receive but one irrigation and this before seeding. The California Mariout variety, as grown in Egypt, is cultivated on the dry hills west of Lake Mariout, where it is grown without irrigation on lands receiving about 8 inches of rainfall.

The barleys on the eastern coast of the Mediterranean are winter-grown. However, they are not characterized by a winter growth habit. White Smyrna is very successful as a spring barley in the western section of the northern Plains. The variety designated as Palmella Blue has not shown great promise in America but is included because of its high resistance to shattering. Trebi is included from Armenia. Trebi is without doubt the most vigorous barley ever introduced by the United States Department of Agriculture and should be a desirable parent to cross with any variety.

Multan and Lyallpur came from India. Each has a suggestion of winter habit and both are high-yielding sorts in the American Southwest. Everest came from the central Asiatic highlands high on the slopes of Mt. Everest. It is characterized by large spikes, large kernels, and a high degree of resistance to summer frost. The peduncle of this variety is curved until the spike is almost on the ground, although the culm would not be described as short. Manchuria and Oderbrucker are similar varieties, the former of which is definitely known to have come from Manchuria. Both of these are well known and need no description. China proper is represented by one variety, Han River. This is the only one secured from China which has shown much promise in the United States.

Four varieties of hybrid origin were included in addition to Golden Pheasant. Two of these, Flynn and Glabron, came from crosses of Lion on Club Mariout and Manchuria, respectively. Alpha is a two-rowed hybrid (Champion of Vermont X Manchuria) which has produced high yields in New York, while Meloy doubtless resulted from a cross of Nepal on Coast.

Among these 28 varieties there is not one that would not attract attention in the part of the United States to which it is adapted. Some of them in themselves would probably never be cultivated on any considerable acreage in this country. Each one of the 300-odd hybrids, however, does have possibilities and this may be a way of utilizing qualities which otherwise could never be used.

# AGRONOMIC AFFAIRS

## SUMMER MEETING OF CORN BELT SECTION

The summer meeting of the Corn Belt Section of the American Society of Agronomy will be held in Kansas on June 12, 13, and 14. The first day and until noon of the second day the sessions will be devoted to a study of the work of the Kansas Agricultural Experiment Station at Manhattan. On the afternoon of the second day the visitors will be taken to the Fort Hays branch station at Hays, Kan., where they will spend the third day.

## COLORADO SEED COUNCIL

At Denver on March 9 the preliminary organization of the Colorado Seed Council was perfected, permanent organization awaiting the acceptance or rejection of membership of organizations proposed as members of the Council. A constitution was adopted similar to the constitutions adopted in other states which have established seed councils.

## NEWS ITEMS

ANNOUNCEMENT is made in *Science* of the establishment of a five-year fellowship for the study of the relation of fertilizers to asparagus culture by the N. V. Potash Export My., at the Massachusetts Agricultural College. The work will be carried on under the direction of V. A. Tiedjens at the Market Garden Field Station at Waltham, and will be conducted on four definite soil types.

C. B. AHLSON, Extension Agronomist, University of Idaho, has resigned to become northwestern branch manager of the Chipman Chemical Engineering Company of Bound Brook, New Jersey. Mr. Ahlson will be located at Boise, Idaho.

J. D. REMSBERG, former member of the teaching and station staff of the Department of Agronomy of the University of Idaho and who has this year been handling the teaching work in agronomy at the Southern Branch of the University at Pocatello, has been appointed Extension Agronomist, University of Idaho, and entered on his new duties on April 1.

E. W. WHITMAN, a candidate for the master's degree in agriculture from the University of Idaho in June, has been appointed to teaching work in agronomy at the Southern Branch of the University at Pocatello.

E. M. JOHNSON, assistant pathologist in the Department of Agronomy, Kentucky Agricultural Experiment Station, has returned from the University of Minnesota, where for the last two quarters he has been doing graduate work toward the Ph.D. degree.

F. E. BEAR has resigned as Professor of Soils, Ohio State University, effective April 1, to become Director of Agricultural Research for the American Cyanamid Company.

R. B. CARR has recently resigned as Assistant Agronomist at the Sandhill Experiment Station, Columbia, S. Car., to accept employment at the Delta Branch Station, Stoneville, Mississippi. J. H. Hunter, a graduate of Clemson College and of the University of Kentucky, has been appointed in his stead.

THE extension agronomists of the northeastern states will hold their summer meeting at West Virginia University, Morgantown, W. Va. The date has not yet been set, but the meeting will probably be held late in July or early in August.

R. J. FRIANT, formerly county agent of Morgan County, West Virginia, has been elected to the position of Extension Agronomist at West Virginia University. Mr. Friant will assume his new duties July 1.

W. H. PIERRE, formerly of the Agronomy Department of the Alabama Experiment Station, has assumed the position of Associate Agronomist at the West Virginia Agricultural Experiment Station. Dr. Pierre will devote practically all of his time to research in soils.

E. S. LYONS, formerly Assistant Professor of the Kansas State Agricultural College, has accepted an appointment with the Bureau of Chemistry and Soils of the U. S. Department of Agriculture.

PRESIDENT Funchess has delegated Dr. Oswald Schreiner, Chief of the Division of Soil Fertility, U. S. Department of Agriculture, to represent the Society at the Fourth Pacific Science Congress to be held in Java in May. Dr. Schreiner will be in the Orient at that time, and plans to attend the Congress.

AN appropriation has been granted by the Saskatchewan Legislative Assembly for the erection and equipment of a building at the University of Saskatchewan to be devoted exclusively to work of the Field Husbandry Department. This building will be modern in every particular and will include suitable offices, laboratories, and class rooms. It will also include a large seed distribution work room and another large room to be devoted to short courses and demonstration work. The building is to be constructed of glaciated lime stone, a deposit of which occurs on land owned by the University. It is expected that it will be ready for occupancy next autumn.

THE Saskatchewan Registered Seed Growers' Limited, an organization devoted to cooperative marketing of pedigreed field seeds, with headquarters at Moose Jaw, Saskatchewan, is to be provided with a modern seed cleaning and distribution plant, an appropriation having been granted by the Dominion Government for this purpose. This plant will be equipped with the latest and most modern devices for cleaning and handling field seeds. It will be held as property of the Dominion Government but will be at the disposal of the cooperative association of growers as above mentioned. This is considered to be a very important forward step in the crop improvement program in this province.

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# INHERITANCE STUDIES IN SEVIER X ODESSA WHEAT CROSS[1]

GEORGE STEWART AND HAROLD PRICE[2]

## INTRODUCTION

Inheritance of certain characters in wheat has been given considerable attention in the past few years. These studies have shown that the genetic behavior of different wheats varies widely. In many of the crosses the characters are inherited in a comparatively simple manner, whereas other crosses show a complex genetic behavior and ratios that are far from simple. Many of the problems in inheritance of wheat are yet to be solved. It is hoped that the present studies contribute somewhat in this direction.

## REVIEW OF LITERATURE

There is at present not a great amount of available literature upon inheritance of awn and spike characters in wheat. After all it must be recognized that it is not possible to find the reaction in any particular cross without studying it.

### AWNS

The awned condition in wheat is regarded by some as being dominant over the awnless condition; others regard lack of awns as dominant.

In India, Howard and Howard (6)[3] obtained a complex segregation of awn characters from a cross between awned and awnless varieties. Five distinct classes were obtained in the ratio of 1 complete awnless to 15 awned. These results were explained upon the basis of a two-factor difference.

[1]Contribution from Department of Agronomy, Utah Agricultural Experiment Station, Logan, Utah. Publication authorized by the Director, January 3, 1929. Received for publication January 9, 1929.

[2]Agronomist in charge of Plant Breeding and graduate student, respectively.

[3]Reference by number is to "Literature Cited," p. 512.

Clark (3), when analyzing his data in a cross between Kota x Hard Federation, found five classes of awn types. He thought two factors were involved, but later has decided there were more as the segregation was very complex.

Nilsson-Leissner (9) and Meyer (7) showed that in spelt x *vulgare* crosses the awns are linked with the spelt and spelt-like forms.

True-breeding forms of awned, half-awned, and awnless wheats were obtained by mutation by Nilsson-Ehle (8). He found awned types to be dominant over half-awned types and half-awned types over awnless types. His results were explained on the basis of multiple allelomorphs for the awned type plants.

Stewart (12) in his crosses between Federation and Sevier obtained four homozygous classes of awns, with the two parental classes more numerous than the two intermediate classes. The segregation was explained by the hypothesis that there were two factors for awns located in the same chromosome and that there was a crossing over of about 35%.

## SPIKE DENSITY

Wheat crosses of the same sub-species or of *vulgare* x *compactum* have usually shown simple segregation.

Biffen (1), Gaines (4), and Spillman (11) report simple 1:2:1 ratios.

Hayes and Harlan (5) explained their results with barley in some cases by a one-factor difference, and in others by a two- or three-factor difference. It was necessary in some cases to assume minor modifying factors in addition to the main factor differences.

Spike density was found by Boshnakian (2) to be correlated with length of straw.

Parker (10), in his crosses of *compactum* x *vulgare*, obtained forms varying from those as compact as the more compact parent to forms decidedly more lax than the lax parent. This work showed the complexity of spike density. The importance of determining density by measurement rather than by sight was emphasized.

Nilsson-Ehle (8) in some crosses found a complex segregation which was explained by supposing factors for one character to be inhibitors for some other character.

Meyer (7) obtained ratios of 1:14:1 in several crosses of dense x lax parents. The intermediates greatly outnumbered the others.

Stewart (12) in crosses of Federation x Sevier found that there was one major and some minor factors concerned in determining spike density. A similar inheritance was found in a cross between Kanred and Sevier (13).

## DESCRIPTION OF PARENTS

The studies herein reported were made upon a cross between pure lines of Sevier and Odessa wheats.

Sevier is an awned variety of spring wheat. Though the head is somewhat compact, it is not a club variety. The chaff is light bronze and the grain white.

Odessa is a winter wheat and is considered to be an awnless type. This wheat, however, has tip awns which vary in length from almost nothing to an occasional single awn of considerable length. The head of this wheat is lax. The chaff is somewhat darker bronze than that of the Sevier parent and is found occasionally to be marked with black spots or stripes. The grain is light red in color.

Observations were made and data taken on the spike density, the length of the culm, the number of culms per plant, the length and segregation of awns, the grain color, the chaff color, and the number of spikelets per head.

From the methods used and the data obtained it was possible to determine the manner of segregation of awns, of spike density, and of the color of the grain. Although the behavior of the other characters would lead to the belief that there was segregation, the nature of the segregation was not determined.

## METHODS OF TAKING AND STUDYING DATA

The cross was made in Logan, Utah, in the summer of 1923. The $F_1$ plants, grown in 1924 at Logan, were spaced about 1 foot apart each way. The $F_2$ plants were grown in rows 1 foot apart, spaced 3 or 4 inches in the row. No data were taken on the $F_2$ plants, except to classify them as to color of grain. The $F_3$ families, one from each $F_2$ plant, were grown under dry-farm conditions at Petersboro, Utah, in 1926. During this year data were taken as to awn classes, spike density, grain color, chaff color, length of the longest culm, number of culms, and number of spikelets per spike. Each figure subsequently reported is the mean of an entire $F_3$ family of 30 to 40 plants each.

The length of the longest culm on each plant was determined by placing the plant upon a board graduated into centimeters. At the foot of the board and perpendicular to it was fastened a foot piece. The roots of the plant were placed against the foot piece and the length of the plant read directly from the base board. The number of culms per plant was determined by separating and counting the culms. The plants were classified as to awns into two types, (a) the awnless type resembling the Odessa parent and (b) the awned type resembling the Sevier parent. The progenies were found to group themselves into three classes, *viz.*, (a) those breeding true

for the awnless type, (b) those breeding true for awns similar to those of the Sevier parent, and (c) those segregating for the two types of awns.

The awn length was determined by inserting a rule under the awn and reading the length in millimeters. These measurements were made uniformly about the middle of the head upon the awned plants and at about the same relative position on the other awn types.

Head density was measured by placing a rule upon the rachis and measuring the length of 10 of the internodes. The measurement of internodes was taken near the middle of the head so as to avoid the variation in internode length which occurs near the ends of the spike.

The color of grain was determined by threshing one head from each plant.

The chaff color was observed and recorded at the time of threshing of the head.

The number of spikelets per head was determined by counting the spikelets on one representative head from each plant.

There were too few parental rows to permit definite conclusions on the characters of length of the longest culm, number of culms per plant, and the number of spikelets per spike. The data on awns and on spike density seem to warrant dependable conclusions.

## EXPERIMENTAL DATA

### AWNS

Work upon the data for awns showed the awns to be segregating into three classes, *viz.*, fully awned, nearly awnless, and intermediate.

Because of slight differences in variation and group variation, it is not safe to depend upon the eye as the sole guide in classification. It is more accurate to measure and compile the measured data so as to place them in a table. Differences in plants which are not discernible to the eye alone, when measured and plotted, are often easily seen. Thus the data have been placed in tables to aid in analysis.

In Table 1 the mean length of the awns by progenies and their mean coefficients of variability are plotted. The results obtained show that there are three distinct groups of plants. Two of the groups have low coefficients of variability, while one of the groups has a high coefficient of variability.

When the two groups with low coefficients of variability are examined as to length of awn, one group resembles the Odessa parent while the other group resembles the Sevier parent. The group having the high coefficients of variability is intermediate in awn length, falling between the other two groups.

TABLE 1.—*Awn length classes of $F_3$ progenies grouped according to the mean length of the awns and coefficients of variability (C. V.) classes.*

| F progenies grown at Petersboro, Utah, in 1926. Length of awns (millimeters) | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 12 | 16 | 20 | 24 | 28 | 32 | 36 | 40 | 44 | 48 | 52 | 56 | 60 | 64 | 68 | 72 | 76 | 80 | 84 | 88 | 92 | 96 | C. V. classes |
| | | | | | | | | | | | | | | | | | | | | | | 4 |
| 1 | | | | | | | | | | | | | | | | | | | | | | 8 |
| | | 1 | | | | | | | | | | 1 | 3 | 5 | | | 2 | | | | | 12 |
| | | 4 | | | 1 | | | | | 1 | 2 | 1 | | | 4 | 2 | 3 | 2 | 1 | | 1 | 16 |
| | 1 | 3 | | | | | 1 | | | | 2 | 2 | 5 | 5 | 5 | 2 | 2 | 3 | | 1 | | 20 |
| | 3 | 5 | 1 | 1 | | | | | 1 | | | 2 | 1 | | | | | | | | | 24 |
| | 2 | 4 | 2 | 1 | 1 | | 1 | | | | | | | | | | | | | | | 28 |
| | 3 | 4 | 2 | | | | | | | | | | | | | | | | | | | 32 |
| | 1 | | 2 | | | | | | | | | | | | | | | | | | | 36 |
| | | 1 | 1 | | | | 1 | 1 | | | | | | | | | 1 | | | | | 40 |
| | | | | | 1 | 2 | 3 | 1 | 3 | 1 | | | | | | | | | | | | 44 |
| | | | | | 1 | 2 | 3 | 2 | 1 | 1 | 1 | | 5 | | | | | | | | | 48 |
| | | | | 2 | 4 | 1 | 7 | 1 | 3 | 2 | | 2 | | | | | | | | | | 52 |
| | | | | | 3 | 8 | 6 | 5 | 1 | 2 | 1 | | | | | | | | | | | 56 |
| | | | | | 3 | 4 | 2 | 2 | 3 | 1 | | | | | | | | | | | | 60 |
| | | | | 1 | 2 | 3 | 2 | 2 | | 2 | | | | | | | | | | | | 64 |
| | | | | 1 | | 1 | 3 | 1 | 1 | | | | | | | | | | | | | 68 |
| | | | | | 2 | | 1 | | | | | | | | | | | | | | | 72 |
| | | | | | | 3 | 1 | | | | | | | | | | | | | | | 76 |
| | | | | 1 | | | | | | | | | | | | | | | | | | 80 |
| | | | | | 1 | | | | | | | | | | | | | | | | | 84 |

TABLE 2.—*Awn length classes of the means of Sevier and Odessa parental rows and of $F_3$ hybrids arranged according to awn length and coefficient of variability (C. V.) classes, grouping the hybrids into three divisions, viz., homozygous dense, heterozygous, and homozygous lax.*

Grown at Petersboro, Utah, in 1926.

| | Length of awns (millimeters) 8 | 12 | 16 | 20 | 24 | 28 | 32 | 36 | 40 | 44 | 48 | 52 | 56 | 60 | 64 | 68 | 72 | 76 | 80 | 84 | 88 | 92 | 96 | Total | C. V. classes | Mean C. V. | Average length |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 1 | | 1 | | | | | | | | | | | | | | | | | | 2 | 25 | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | 33 | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | 41 | | |
| | | | 1 | 1 | | | | | | | | | | | | | | | | | | | | 2 | 49 | | |
| Odessa | | | 1 | | | | | | | | | | | | | | | | | | | | | 1 | 57 | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | 65 | | |
| | | 1 | | | | | | | | | | | | | | | | | | | | | | 1 | 73 | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | 81 | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | 89 | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | 97 | | |
| | 1 | | | | | | | | | | | | | | | | | | | | | | | 1 | 105 | | |
| Total | 1 | 1 | 2 | 2 | | 1 | | | | | | | | | | | | | | | | | | 7 | | 59.95 | 16.96 |
| | | | | | | | | | | | | | | | | 3 | 2 | | | | | | | 5 | 9 | | |
| Sevier | | | | | | | | | | | | | 1 | | 2 | | | | | | | | | 3 | 17 | | |
| Total | | | | | | | | | | | | | 1 | | 2 | 3 | 2 | | | | | | | 8 | | 12.51 | 62.03 |
| | | 1 | | 1 | | | | | | | | | | | | | | | | | | | | 2 | 9 | | |
| Homozygous | | | 1 | 7 | | | 1 | | 1 | | | | | | | | | | | | | | | 10 | 17 | | |
| awnless* | | | 5 | 9 | 3 | 2 | 1 | | 1 | | | | | | | | | | | | | | | 21 | 25 | | |
| | | | 4 | 4 | 4 | | | | | | | | | | | | | | | | | | | 12 | 33 | | |
| | | | | 1 | 1 | | | | | | | | | | | | | | | | | | | 2 | 41 | | |
| Total | | 1 | 10 | 22 | 8 | 2 | 2 | | 2 | | | | | | | | | | | | | | | 47 | | 25.34 | 21.36 |

| | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 4 | 2 | 3 | 1 | | | | | | 1 | | | | | | 14 | 33 | | |
| | 2 | 5 | 3 | 10 | 3 | 4 | 3 | 1 | 2 | 5 | | | | | | | | | 38 | 41 | | |
| Heterozygous | | 6 | 12 | 8 | 7 | 4 | 3 | 1 | | | | | | | | | | | 41 | 57 | | |
| | 2 | 2 | 4 | 5 | 3 | 1 | 2 | | | | | | | | | | | | 19 | 65 | | |
| | | 2 | 3 | 2 | | | | | | | | | | | | | | | 7 | 73 | | |
| | 1 | 1 | | | | | | | | | | | | | | | | | 2 | 81 | | |
| Total | 5 | 17 | 24 | 29 | 15 | 12 | 9 | 2 | 2 | 5 | | | 1 | | | | | | 121 | | 54.90 | 41.65 |
| | | | | | | | | | 1 | 3 | 5 | | | 2 | | | | | 11 | 9 | | |
| Homozygous | | | | | | | 1 | 4 | 3 | 5 | 5 | 9 | 4 | 5 | 5 | 1 | 1 | 1 | 44 | 17 | | |
| awned | | | | | | 1 | | | 2 | 1 | | | | | | | | | 4 | 25 | | |
| | | | | | | | | | | | | | | | | | | | | 33 | | |
| Total | | | | | | 1 | 1 | 4 | 6 | 9 | 10 | 9 | 4 | 7 | 5 | 1 | 1 | 1 | 59 | | 16.05 | 70.30 |

*There were 14 true-breeding awnless plants of which the awns were so short as not to have been measured. These families are omitted from this table, but included in Table 3.

Between the two groups having low coefficients of variability are three families which cannot be readily assigned to any group. When viewed from the standpoint of coefficients of variability, it seems that they should belong to one or the other of the groups resembling the parents; but from the standpoint of awn length, they seem to belong with the intermediate group. It is possible that environment may have influenced these families to grow as they did. By growing families from these plants in $F_4$ it can be determined where they belong. In Table 2 these plants were placed two in the homozygous awnless group and one in the homozygous lax group.

By placing the $F_3$ families in a table along with the parental check plants, as is done in Table 2, the nature and extent of the segregation can be seen. The range in awn length of the parent plants is from 8 mm in Odessa to 68 mm in Sevier. The range in the hybrid is from 12 to 96 mm. It is seen from this that the progenies have a greater range than do their parents.

Odessa, the short-awned parent, has a range from 8 to 24 mm. The range of the homozygous short-awned hybrid is from 12 to 40 mm. Likewise, the range of awn length in Sevier is from 52 to $68 \pm 5.70$ mm. In the homozygous long-awned hybrid the range is from 54 to $96 \pm 6.34$ mm. In this group the range is extended in the direction of longer awns.

The mean length of awns of all Odessa parents equals 16.96 mm. The mean awn length of the true-breeding, short-awned hybrid is 21.36 mm. The mean awn length of all Sevier parents is 62.03 mm. The mean length of awns of the long-awned hybrid is 70.30 mm. In the case of both the homozygous hybrids there is a tendency for the awns to be longer than the awns of the corresponding parental types. This breeding behavior would suggest that there might be a factor or a combination of factors which influence the awn growth of the hybrid progenies in such a way as to cause unusual length. The small number of parental rows, however, probably did not show their entire range.

A count of the number of families in each group shows that there are 61 awnless, 121 intermediates, and 59 awned. This is an excellent 1:2:1 ratio.

Table 3 shows the calculated and the observed number of families and the closeness of fit when compared with what would be expected on the basis of a one-factor difference. Theoretically, with the number of families involved, there should be a segregation of 60.25 : 120.50 : 60.25. The actual segregation was 61:121:59. From this table it is seen that P is very high, probably about 95. There

are, therefore, about 95 chances out of 100 that a worse fit migth occur from chance alone. The evidence is very strong, therefore, that there is one main factor difference influencing awn class segregation.

TABLE 3.—*Closeness of fit of calculated to observed numbers on the basis of one factor involved, i. e., 1:2:1 ratio.*

Grown at Petersboro, Utah, in 1926.

| | C | O | (O-C) | $(O-C)^2$ | $\frac{(O-C)^2}{C}$ |
|---|---|---|---|---|---|
| Homozygous awnless | 60.25 | 61 | 0.75 | 0.5625 | 0.0093 |
| Heterozygous | 120.50 | 121 | 0.50 | 0.2500 | 0.0021 |
| Homozygous awned | 60.25 | 59 | 1.25 | 1.5625 | 0.0259 |
| | | | | $X^2$ = | 0.0373 |
| | | | | | P is very high |

## SPIKE DENSITY

There was a visible segregation for spike density, yet it became difficult to place the families in the class to which they belonged, especially when the plants approached the upper limits of the dense group or the lower limits of the lax group. Table 4 was used, therefore, to determine segregation. The families were placed in the table according to their coefficients of variability and according to the mean length of 10 internodes.

From the table it is seen that there is a distinct grouping. There are two classes having a low mean coefficient of variability. The means of these are 9.60% and 11.03%. The third class, with a high coefficient of variability, has a mean coefficient of 27.86%.

The two groups having the low mean coefficients of variability are regarded as true-breeding forms. The other class is regarded as segregating. A count of these groups shows that they are in the ratio of 55:126:60 which is a very good approximation to a 1:2:1 ratio.

In order to compare the progenies with the parental types, Table 5 was prepared. In the table the parental varieties and the groups obtained in Table 4 were plotted according to the mean length of 10 internodes and according to the mean coefficients of variability.

The range in length of 10 internodes was greater in the hybrids than it was in the parents. The shortest mean length of 10 internodes in the Sevier parental rows was 29.83±1.92 mm. The longest for the Odessa rows was 47.52±1.93 mm. In the progenies the range was from 20.65±1.35 mm, the shortest, to 64.25±3.19 mm, the longest. In the homozygous lax group of hybrids, there were only six families with mean internode lengths as low as the greatest

TABLE 4.—*$F_3$ progenies grouped according to mean spike density classes and coefficient of variability (C. V.) classes, giving three groups, one with high C. V. and two with low C. V. classes.*

Grown at Petersboro, Utah, 1926.

Length of 10 spikelet internodes (millimeters)

| C.V. classes | 20 | 22 | 24 | 26 | 28 | 30 | 32 | 34 | 36 | 38 | 40 | 42 | 44 | 46 | 48 | 50 | 52 | 54 | 56 | 58 | 60 | 62 | 64 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4 | | | | | | | | | | | | | | | | | | | | | 1 | | |
| 6 | | | | | | 1 | 1 | | | | | | | | | | | | 1 | 2 | 1 | | |
| 8 | | | 1 | 5 | 4 | 1 | 1 | | | | | | | | 1 | 3 | 2 | 4 | 4 | 2 | 2 | 2 | 2 |
| 10 | 1 | 2 | 7 | 3 | | 3 | 1 | 1 | 1 | 2 | | | | 1 | 2 | 3 | 4 | 1 | 2 | | 1 | | |
| 12 | | 3 | 3 | 3 | 3 | | 1 | | | | | | | | 1 | 1 | 2 | | 3 | 2 | | | |
| 14 | | | 1 | 1 | 2 | 1 | | | | | | | | | | 1 | | | | 1 | 1 | | |
| 16 | | 1 | 2 | 1 | | | | | | | | | | | | | | 1 | | | | | |
| 18 | | 1 | | 1 | 1 | | | | 1 | | | | | 1 | | | | | | | | | |
| 20 | | | | | | | | 1 | | | | 1 | | | | | | | | | | | |
| 22 | | | | | | | 1 | | 4 | 4 | 4 | | 1 | 1 | | | | | | | | | |
| 24 | | | | | | | 2 | 4 | 5 | 3 | 3 | 2 | | | | | | | | | | | |
| 26 | | | | | | | 2 | 4 | 6 | 4 | 2 | 3 | | | | | | | | | | | |
| 28 | | | | | 1 | | 1 | 4 | 7 | 7 | 2 | | 3 | 1 | | 1 | | | | | | | |
| 30 | | | | | 1 | 1 | 1 | 1 | 3 | 6 | 3 | 1 | 1 | | 1 | | | | | | | | |
| 32 | | | | | | | 1 | 1 | 2 | 3 | | | 1 | | | | | | | | | | |
| 34 | | | 1 | | | | 1 | 1 | 1 | | 2 | 1 | | | | | | | | | | | |
| 36 | | | | | | | | 1 | 1 | | | | | | | | | | | | | | |
| 38 | | | | | | | 1 | | | 2 | | | | | | | | | | | | | |
| 40 | | | | 1 | | | | | | | | | | | | | | | | | | | |
| 42 | | | | | | | | | | | | | | | | | | | | | | | |
| 44 | | | | | | 1 | | | | | | | | | | | | | | | | | |

mean internode length of the lax parent and no families with as low mean internode length as the mean length of the lax parental checks. The lowest mean internode length of the lax hybrid was 46 mm. The mean internode length for all Odessa plants is 45.99 mm. The mean internode length of all the true-breeding lax hybrid progenies is 55.79 mm. In the homozygous dense group of hybrids the average length of internodes is 26.97 mm.

The mean internode length of the Sevier parent was 31.99 mm. The true-breeding dense hybrids were, on the whole, shorter of internode length than were the Sevier parent. The true-breeding lax progenies are longer of internode than the Odessa parent. The mean internode length of the heterozygous hybrids is between the mean of the two parents.

When the observed number of families in each group is compared with the calculated number which would be expected when a one-factor difference is assumed, the results shown in Table 6 are obtained. P in this case is very high, being about 0.72. From the law of chance, a worse fit would be expected 72 out of 100 times.

There is good evidence, therefore, that in the segregation of spike density classes a one-factor difference is involved.

### GRAIN COLOR

The segregation for grain color was easily seen and the number in each class easily counted. There were three grain classes according to color, *viz.*, (a) true red, (b) true white, and (c) a type segregating for red and white grain.

The goodness of fit between the observed and calculated numbers in each class, when it is assumed that there is a one-factor difference, is shown in Table 7. From this table it is seen that the fit is not good. P is very low because of too great a variation between calculated and observed numbers of families in each group. The poor fit is caused by a shortage in the number of families breeding true for white grain and by too great a number of segregating families. The number of segregating families in excess of the expected number is about equal to the number lacking in the true-breeding white class. If the variation were due to chance, there would likely be about equal variation in all classes from the expected number. In the one class, however, the variation is negligible. These families were unavoidably grown upon land which had been seeded to Kanred wheat the year before. It is entirely possible, therefore, that some volunteer red wheat could have gotten into the homozygous white class and have been overlooked. If this has been the case, it would have caused some true-breeding white families to have been placed in the heterozygous

TABLE 5.—*Odessa and Sevier parents, together with the $F_3$ progenies grouped according to mean density of 10 internodes and according to the coefficients of variability (C. V.) classes.*

Grown at Petersboro, Utah, in 1926.

| | Length of 10 spikelet internodes (millimeters) | | | | | | | | | | | | | | | | | | | | | | | Total | C. V. classes | Mean C. V. | Average length |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 20 | 22 | 24 | 26 | 28 | 30 | 32 | 34 | 36 | 38 | 40 | 42 | 44 | 46 | 48 | 50 | 52 | 54 | 56 | 58 | 60 | 62 | 64 | | | | |
| | | | | | | | | | | | | | | 2 | 1 | | | | | | | | | 3 | 6 | | |
| | | | | | | | | | | | | | | 1 | 1 | | | | | | | | | 2 | 8 | | |
| Odessa | | | | | | | | | | | | | 1 | | | | | | | | | | | 1 | 10 | | |
| | | | | | | | | | | | | | | 1 | | | | | | | | | | 1 | 12 | | |
| Totals | | | | | | | | | | | | | 1 | 4 | 2 | | | | | | | | | 7 | | 7.78 | 45.99 |
| | | | | | | | 1 | | | | | | | | | | | | | | | | | 1 | 6 | | |
| Sevier | | | | | | 1 | 2 | 1 | | | | | | | | | | | | | | | | 4 | 8 | | |
| | | | | | | 1 | 2 | 1 | | | | | | | | | | | | | | | | 4 | 10 | | |
| Totals | | | | | | 2 | 5 | 2 | | | | | | | | | | | | | | | | 9 | | 8.46 | 31.99 |
| | | | | | | 1 | 1 | | | | | | | | | | | | | | | | | 2 | 6 | | |
| | | 2 | 1 | 5 | 4 | 1 | 1 | | | | | | | | | | | | | | | | | 12 | 8 | | |
| Homozygous | 1 | 2 | 7 | 3 | | 3 | 1 | 1 | 1 | 2 | | | | | | | | | | | | | | 21 | 10 | | |
| Dense | | 3 | 3 | 3 | 3 | | 1 | | | | | | | | | | | | | | | | | 13 | 12 | | |
| | | | 1 | 1 | 2 | 1 | | | | | | | | | | | | | | | | | | 5 | 14 | | |
| | | 1 | 2 | 1 | | | | | | | | | | | | | | | | | | | | 4 | 16 | | |
| | | 1 | | 1 | 1 | | | | | | | | | | | | | | | | | | | 3 | 18 | | |
| Totals | 1 | 7 | 14 | 14 | 10 | 6 | 4 | 1 | 1 | 2 | | | | | | | | | | | | | | 60 | | 11.03 | 26.97 |

| | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Heterozygous | | | | | | | I | | | | | | | | | | | | | | I | 18 | | |
| | | | | | | I | | | | I | | | | | | | | | | | 2 | 20 | | |
| | | | | | I | | 4 | 4 | 4 | | I | I | | | | | | | | | 15 | 22 | | |
| | | | | | 2 | 4 | 5 | 3 | 3 | 2 | | | | | | | | | | | 19 | 24 | | |
| | | | | | 2 | 4 | 6 | 4 | 2 | 3 | | | | | | | | | | | 21 | 26 | | |
| | | | I | | I | 4 | 7 | 7 | 2 | | 3 | I | | I | | | | | | | 27 | 28 | | |
| | | | I | I | I | I | 3 | 6 | 3 | I | I | | I | | | | | | | | 19 | 30 | | |
| | | | | | I | I | 2 | 3 | | | I | | | | | | | | | | 8 | 32 | | |
| | I | | | | I | I | I | | 2 | I | | | | | | | | | | | 7 | 34 | | |
| | | | | | | I | I | | | | | | | | | | | | | | 2 | 36 | | |
| | | I | | | I | | | 2 | | | | | | | | | | | | | 3 | 38 | | |
| | | | | | | | | | | | | | | | | | | | | | | 40 | | |
| | | | | I | | | | | | | | | | | | | | | | | I | 44 | | |
| Totals | I | I | 2 | 2 | 10 | 17 | 30 | 29 | 16 | 8 | 6 | 2 | I | I | | | | | | | 126 | | 27.86 | 37.11 |
| Homozygous Lax | | | | | | | | | | | | | | | | | | I | | | I | 4 | | |
| | | | | | | | | | | | | | | | | I | 2 | I | | | 4 | 6 | | |
| | | | | | | | | | | | | | I | 3 | 2 | 4 | 4 | 2 | 2 | 2 | 2 | 22 | 8 | | |
| | | | | | | | | | | | | I | 2 | 3 | 4 | I | 2 | | I | | | 14 | 10 | | |
| | | | | | | | | | | | | | I | I | 2 | | 3 | 2 | | | | 9 | 12 | | |
| | | | | | | | | | | | | | | I | | | | I | I | | | 3 | 14 | | |
| | | | | | | | | | | | | | | | | | I | | | | | I | 16 | | |
| | | | | | | | | | | | | I | | | | | | | | | | I | 18 | | |
| Totals | | | | | | | | | | | | 2 | 4 | 8 | 8 | 6 | 10 | 7 | 6 | 2 | 2 | 55 | | 9.60 | 55.79 |

group and would account in part for the discrepancy. Chance and the above possibility could cause such a variation as exists in this case.

TABLE 6.—*Closeness of fit of observed to expected number of progenies in each spike density group when a one-factor difference, i.e., a 1:2:1 ratio, is assumed.*

Grown at Petersboro, Utah, in 1926.

| | C | O | (O-C) | $(O-C)^2$ | $\frac{(O-C)^2}{C}$ |
|---|---|---|---|---|---|
| Homozygous dense | 60.25 | 55 | 5.25 | 27.5625 | 0.4575 |
| Heterozygous | 120.50 | 126 | 5.50 | 30.2000 | 0.2510 |
| Homozygous lax | 60.25 | 60 | 0.25 | 0.0625 | 0.0014 |
| | | | | | $X^2 = 0.7099$ |
| | | | | | P is very high |

Judging by $F_4$ and $F_5$ behavior, it is probable that the segregation is due to a one-factor difference and should be in a ratio of 1:2:1.

## CHAFF COLOR

The chaff color of the two grains was so nearly alike that it was impossible to tell if there was segregation. A considerable number of progenies had black markings upon the chaff similar to the occasional markings on the Odessa parent. In some cases the outer glumes were almost black, so much so as to give the head a black appearance. The markings were of various degrees, from almost black glumes to those where only a few specks of black were on the lower glumes. There was also great variation in the amount of black on the heads growing on the same plant.

TABLE 7.—*Observed and calculated number of plants in each grain color group when C is based on the assumption that the segregation is due to a one-factor difference.*

Grown at Petersboro, Utah, in 1926.

| | C | O | (O-C) | $(O-C)^2$ | $\frac{(O-C)^2}{C}$ |
|---|---|---|---|---|---|
| Homozygous red | 60.25 | 59 | 1.25 | 1.5625 | 0.0242 |
| Heterozygous | 120.50 | 139 | 18.5 | 342.25 | 2.8402 |
| Homozygous white | 60.25 | 43 | 17.25 | 297:56 | 4.9386 |
| | | | | | $X^2 = 8.0030$ |
| | | | | | P = 0.018 |

A number of heads from the most intensely marked plants were collected and grown. From the studies made of these progenies it was decided that the markings were greatly influenced by environment, although the tendency to respond to a certain environment in this way may be inherited. The nature of inheritance was not determined.

TABLE 8.—*Sevier and Odessa parents and $F_3$ progenies arranged according to the mean of the longest culm and the standard deviation (S. D.) classes.*

Grown at Petersboro, Utah, in 1926.

| | Length of longest culm classes, cm. | | | | | | | | | | | | | | Total | S. D. classes | Mean S. D. | Average of longest culm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 70 | 74 | 78 | 82 | 86 | 90 | 94 | 98 | 102 | 106 | 110 | 114 | 118 | 122 | | | | |
| | | | | | | | | 1 | 1 | | | | | | 2 | 6 | | |
| Odessa | | | | | | | | | 2 | 1 | | | | | 3 | 8 | | |
| | | | | | | | 2 | | | | | | | | 2 | 10 | | |
| | | | | | | | | | | | | | | | | 12 | | |
| Totals | | | | | | | 2 | 1 | 3 | 1 | | | | | 7 | | 8.26 | 99.90 |
| | | | | | | | | 2 | 1 | | | | | | 3 | 6 | | |
| Sevier | | | | | | | 1 | | 1 | 1 | | 1 | | | 4 | 8 | | |
| | | | | | | | | | | | | | | | | 10 | | |
| | | | | | | | 1 | | | | | | | | 1 | 12 | | |
| Totals | | | | | | | 2 | 2 | 2 | 1 | | 1 | | | 8 | | 7.43 | 102.55 |
| | | | | | | | | 1 | | 2 | | | | | 3 | 4 | | |
| | | | | | 2 | | 1 | 8 | 3 | 11 | 5 | 9 | 4 | 2 | 45 | 6 | | |
| $F_3$ families | 1 | | | 2 | 3 | 7 | 10 | 12 | 11 | 17 | 18 | 16 | 6 | 4 | 107 | 8 | | |
| | | | | | 4 | 4 | 11 | 10 | 9 | 12 | 8 | 4 | 2 | 1 | 65 | 10 | | |
| | | | | 1 | 1 | 1 | 2 | 3 | 2 | 4 | 2 | | | | 16 | 12 | | |
| | | | | | | | | 1 | 1 | 1 | 1 | | | | 4 | 14 | | |
| | | | | 1 | | | | | | | | | | | 1 | 16 | | |
| Totals | 1 | | | 4 | 10 | 12 | 24 | 35 | 26 | 47 | 34 | 29 | 12 | 7 | 241 | | 8.45 | 103.04 |

### LONGEST CULM

The data assembled for the longest culm are given in Table 8. It is not clear from the few parental rows that there is much difference in mean culm length of the parental varieties. Odessa's mean height was 99.9 cm. The mean height of Sevier was 102.5 cm. There is not only little difference between the two parents, but there is little difference in the variations of the parents. The mean height of the shortest row of Odessa was $83.52 \pm 7.53$ cm, and that of the longest $106.00 \pm 4.92$ cm. In the Sevier the mean of the shortest row was $94.93 \pm 7.53$ cm, and that of the longest $113.12 \pm 4.93$ cm. In the $F_3$ families the average height of the shortest row was $71.91 \pm 5.95$ cm and the average of the longest $123.35 \pm 3.51$ cm. The mean for all $F_3$ families was 103.04 cm. There is a much wider range of culm length in the hybrid progenies than in the parents. There are both shorter mean culm lengths and longer mean culm lengths than there are in the parents. The parental rows, however, were too few to warrant definite conclusions. The tendency, nevertheless, seems to be for the hybrids to have on the average longer culms than even the longer culmed parent.

The mean variability of the hybrid is not far different from that of either parent. The parental mean coefficient of variability for Odessa was 8.27% and for Sevier 7.25%. The hybrid variation was 8.20%.

### NUMBER OF CULMS

Table 9 shows that there is no great variation between the mean number of culms per plant in the two parental families and in the hybrid families. The lowest mean number of culms per plant in the Odessa parent is 6 and the highest mean number is 9. In the Sevier parent the least number of culms per plant is 8 and the greatest mean number of culms per plant is 12. In the hybrid progenies the lowest average number of culms per plant was 4 and the average of the highest culm-bearing progeny was 14. In the hybrids the range is from a few culms less than the lowest parental row to a few higher than the greatest number in the highest parental row.

The Odessa parent has an average number of culms per plant of 7.98, while Sevier has an average number of culms per plant of 10.12. The $F_3$ plants have an average of 9.54 which is between the average of the parents, but it is seen that the trend is considerably toward the Sevier parent.

### NUMBER OF SPIKELETS

From Table 10 it will be noted that there is little variation in the number of spikelets per spike in the two parent wheats.

TABLE 9.—*Mean number of culms per plant of the parents and hybrid progenies.*

| | Number of culm classes | | | | | | | | | | | Total | S. D. classes | Mean S. D. | Average number culms per plant |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | | | | |
| | | | 1 | 1 | | | | | | | | 2 | 2 | | |
| Odessa | | | | 1 | 3 | | | | | | | 4 | 4 | | |
| | | | | | | 1 | | | | | | 1 | 6 | | |
| | | | | | | | | | | | | | 8 | | |
| Totals | | | 1 | 2 | 3 | 1 | | | | | | 7 | | 3.34 | 7.98 |
| | | | | | | | | | | | | | 2 | | |
| | | | | | 1 | 3 | 1 | 1 | 1 | | | 7 | 4 | | |
| Sevier | | | | | | 1 | | | | | | 1 | 6 | | |
| | | | | | | | | | | | | | 8 | | |
| Totals | | | | | 1 | 4 | 1 | 1 | 1 | | | 8 | | 4.25 | 10.12 |
| | | | 4 | 5 | 3 | 4 | 3 | | | | | 19 | 2 | | |
| | 1 | | 4 | 26 | 38 | 55 | 40 | 16 | 5 | 1 | | 186 | 4 | | |
| Hybrid | | | | | 4 | 5 | 8 | 9 | 2 | 5 | 1 | 34 | 6 | | |
| | | | | 1 | | | | | | | | 1 | 8 | | |
| | | | | | 1 | | | | | | | 1 | 10 | | |
| | | | | | | | | | | | | | 12 | | |
| Totals | 1 | | 8 | 32 | 46 | 64 | 51 | 25 | 7 | 6 | 1 | 241 | | 4.15 | 9.54 |

In the Odessa parent the variation in mean number of spikelets per spike varies from 15 in the lowest row to 17 in the highest family. The Sevier parent has a variation in mean number of spikelets per spike of from 12 in the lowest to 15 in the highest. The variation in mean number of spikelets per head in the $F_3$ progenies is from 11 to 20. The lowest mean number of spikelets per head in the hybrid is fewer than the least number in the Sevier parent, while the greatest average number of spikelets per head in the progeny is in excess of the mean number in the Odessa parent. The average number of spikelets per head in the Odessa parent is 16.94, and in the Sevier parent, 14.78. That of the $F_3$ progeny is 16.63. This average for the hybrid is intermediate with respect to the parents but is much nearer the average for the high parent.

The results here obtained would lead one to believe that there may be segregation for number of spikelets per spike, but from the data available, its nature was not determined.

## SUMMARY

A genetic study was made of the $F_3$ progenies of a cross of pure lines of Odessa x Sevier wheats.

The characters in which these parents were contrasted and upon which a study was made included (a) awns, (b) spike density, (c) grain color, (d) length of culm, (e) number of culms per plant, and (f) number of spikelets per spike.

TABLE 10.—*Parental rows and $F_3$ progenies arranged according to mean number of spikelets and according to standard deviation (S. D.) classes.*

Grown at Petersboro, Utah, in 1926.

| | Number of spikelet classes | | | | | | | | | | | Total | S. D. classes | Mean S. D. | Average number of spikelets |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | | | | |
| | | | | | | 2 | 1 | 4 | | | | 7 | 2 | | |
| Odessa | | | | | | | | | | | | | 4 | | |
| | | | | | | | | | | | | | 6 | | |
| Totals | | | | | | 2 | 1 | 4 | | | | 7 | | 2.67 | 16.94 |
| | | | 1 | 1 | 3 | 3 | | | | | | 8 | 2 | | |
| Sevier | | | | | | | | | | | | | 4 | | |
| | | | | | | | | | | | | | 6 | | |
| Totals | | | 1 | 1 | 3 | 3 | | | | | | 8 | | 1.91 | 14.78 |
| | | 1 | | 3 | 19 | 37 | 63 | 48 | 32 | 13 | 3 | 219 | 2 | | |
| Hybrid | | | | | 1 | | 4 | 4 | 3 | 2 | | 14 | 4 | | |
| | | | | | | | | | | | | | 6 | | |
| Totals | | 1 | | 3 | 20 | 37 | 67 | 52 | 35 | 15 | 3 | 233 | | 2.29 | 16.63 |

From this cross three classes of awns were obtained, *viz.*, (a) a homozygous group resembling the Odessa parent, (b) a homozygous group resembling the Sevier parent, and (c) a heterozygous group segregating for awn classes. In the homozygous hybrids there is a greater variation than is found in the parents. In both groups of true-breeding strains there is a tendency for the awns to be longer than those of the corresponding parental group. A good 1:2:1 ratio was obtained in awn segregation.

There was a 1:2:1 ratio in spike density segregation. In the two homozygous groups there were found spikes considerably more compact than the spikes of either parent and some considerably more lax than was found in either parent. The true-breeding dense hybrids have, on the whole, shorter internode lengths than either parent, and the true-breeding lax hybrid had, on the whole, longer internode lengths than has the lax parent. In a few cases both the dense and the lax parental spike forms were recovered.

Although a poor $F_3$ ratio was obtained in grain color segregation, observations in $F_4$ and $F_5$ indicate that inheritance of this character is probably due to a one-factor difference.

No genetical data for chaff color were obtained because of the similarity of the chaff color in the parents. Black markings occurring on the Odessa parent and on some of the progeny were too strongly influenced by environment to permit a determination of the ratios.

There was little difference in the mean length of culms for the parents. The mean length for the hybrids as a group was slightly longer than the mean for the taller parent. There was considerably greater variation in the mean length of the hybrid families than there was in the means of the parental families. The variation reached both above and below the extremes of the parents. Too few parental rows decrease the weight of conclusions on culm length, number of culms, and number of spikelets.

The average number of culms per plant in the hybrid was between the averages for the two parents. The average of the hybrids, however, was considerably toward the average of the parent bearing the greater number of culms.

The lowest number of spikelets per spike in the hybrid is fewer than the least number in the parent with the lower average. The greatest number of spikelets per spike in the progeny is in excess of the greatest number of the high parent. The average number of spikelets per spike in the hybrids is between the average of the parents but is very near the average of the high spikelet bearing parent. None of these differences are statistically significant.

There is perhaps segregation for the number of spikelets, but its nature was not determined.

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# EFFECT OF SIZE OF SEED PIECE AND RATE OF PLANTING ON YIELDS OF WHITE POTATOES[1]

HOWARD B. SPRAGUE AND E. E. EVAUL[2]

There has been a marked rehabilitation of the potato industry in New Jersey in the past few years (1)[3] due in part to a reduction in acreage so that only the most suitable soils are planted to the crop. In addition, a pronounced increase in the use of certified seed of desirable varieties, combined with the adoption of disease control measures and better cultural methods has contributed to more economical production. With the above developments in production methods, the problem of the best size of seed piece and rate of planting has become rather important.

It is obvious that the most profitable combination of rate of planting and size of seed piece will be that which makes the most efficient use of the soil and climate at hand. Seed pieces should be large enough to give the young plants a vigorous start and they must be so spaced that all parts of the upper soil horizons contribute moisture or nutrients to the growing plants. Over-population of plants is to be avoided since the reserve supplies of nutrients and moisture must carry the plants through critical periods when shortages of these are likely to occur.

Although much work has been reported on various phases of the problem under a wide range of conditions, it is still a moot question. Perhaps one should not expect any set of experiments to yield the solution of the problem for any other region than where they were carried out. However, if such experiments are carefully conducted, they should throw some light on the causes underlying the observed results as well as indicating the most profitable empirical practices. During the three years 1924–26, experiments of this nature have been conducted in central New Jersey where the crop is grown intensively on a comparatively large acreage.

## EXPERIMENTAL METHODS

Certified Maine-grown tubers of the Green Mountain variety were used each year, the tubers being in good condition at the time of cutting seed. The seed pieces were cut in three sizes, *viz.*, ½ ounce, 1 ounce, and 1½ ounces, by hand during the period of about two

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[3]Reference by number is to "Literature Cited," p. 523.

weeks preceding planting. Each piece was cut to weight, taking care that at least one eye was included per piece. The cut surfaces were dusted with sulfur and the seed stored in a cool place until planted.

At planting time, the pieces were set by hand in furrows opened with a one-row planter. Correct spacing was obtained by stretching a line along the opened row, the spaces on the line being marked with knots of colored twine. After planting, the pieces were covered with a potato planter adjusted so that only the covering disks in the rear operated.

The rows in these tests were 33 inches apart. The ½-ounce seed pieces were spaced 12, 9, 7½, and 6 inches in the row, thus making the rates of plantings 8.25, 11.0, 13.2, and 16.5 bushels of seed per acre, respectively. The 1-ounce seed pieces were spaced 18, 15, 12, and 9 inches in the row, requiring 11.0, 13.2, 16.5, and 22.0 bushels of seed per acre for these respective spacings. The 1½-ounce seed pieces were spaced 22½, 18, 13½, and 9 inches apart in the row to make the rates of planting 13.2, 16.5, 22.0, and 33.0 bushels of seed per acre for the respective spacings.

Each of the 12 treatments was planted in duplicate plats in 1924 and in triplicate plats in 1925 and 1926. The plats were systematically distributed so that each treatment apparently had an equal chance as far as soil was concerned. All plats contained three rows each of which the center row only was harvested for yield. The desirability of discarding border rows under the conditions of these experiments has been previously noted (2). The plats were 130 feet long in 1924, of which 125 feet were harvested, while in 1925 and 1926, the plats were 105 feet long, 100 feet of which were harvested for yield.

In 1924 the experiment was located on a potato farm near Farmingdale in Monmouth County on Sassafras fine sandy loam. A 4-8-7 fertilizer was applied at the rate of 1,000 pounds per acre in the row before planting, and an equal amount of the same fertilizer was applied as a side dressing after the plants were well up. The seed pieces were set and covered on April 24. The plants grew satisfactorily and matured normally in August. The crop was harvested and weighed October 5 and 6.

In 1925 the experiment was located on Sassafras sandy loam near Jamesburg in Middlesex County. A 5-8-7 fertilizer was applied at the rate of 1,000 pounds per acre in the row before planting. Planting took place on April 9 on a well-prepared seedbed. Satisfactory growth was made by the plants, but weeds became plentiful toward the end of the season. The tubers were dug and weighed on September 12.

In 1926 the experiment was located on the College Farm at New Brunswick. The soil used was a Sassafras silt loam with fairly good drainage. Sulfur at the rate of 100 pounds per acre was added during seedbed preparation to counteract the effect of lime applied to previous crops of hay. A 4–8–5 fertilizer was applied in the row prior to planting at the rate of 1,200 pounds per acre. Planting occurred on April 25 and a good stand was secured. The crop was sprayed with bordeaux mixture on June 10 and 17 and calcium arsenate dust was used during the season to control leaf eating insects. The tubers were harvested when fully matured.

In 1925 and again in 1926, 100 representative hills of each treatment were harvested to determine the effect of size of seed piece and spacing in the row on the number, size, and weight of the tubers formed per hill. These hills were harvested before the balance of the crop was dug and each tuber was weighed individually.

## WEATHER CONDITIONS

The weather conditions for the period of testing are indicated in Table 1. The data for 1924 and 1925 are those recorded at the nearest weather stations, namely, Lakewood and Runyon. Precipitation was plentiful during April and May in 1924, but was somewhat below normal in July. The distribution for all three years is given in Fig. 1. Both the mean temperature and the total effective temperature (temperatures above 45°F) were similar in 1924 and 1926 (Table 1). The season opened earlier and temperatures were higher in 1925 than in the other years. Since planting took place two weeks earlier in 1925 than in the other years, the temperatures occurring during similar stages of growth of the plant were approximately the same in all three years. The general trend of temperatures is shown in Fig. 1.

TABLE 1.—*Climatic conditions from April to August, inclusive, for the three years of the experiment.*

| Station | April | May | June | July | August |
|---|---|---|---|---|---|
| Monthly Mean Temperature in Degrees | | | | | |
| Lakewood, 1924 | 46.8 | 56.5 | 66.0 | 71.5 | 70.9 |
| Runyon, 1925 | 49.6 | 56.1 | 73.0 | 71.4 | 70.1 |
| New Brunswick, 1926 | 46.7 | 59.8 | 64.9 | 73.7 | 72.8 |
| Total Monthly Precipitation in Inches | | | | | |
| Lakewood, 1924 | 5.99 | 5.85 | 6.06 | 1.99 | 5.32 |
| Runyon, 1925 | 2.18 | 2.81 | 2.40 | 4.03 | 1.75 |
| New Brunswick, 1926 | 1.79 | 2.11 | 2.70 | 4.62 | 8.30 |
| Total Monthly Heat Units | | | | | |
| Lakewood, 1924 | 54.0 | 356.5 | 630.0 | 821.5 | 802.9 |
| Runyon, 1925 | 138.0 | 344.1 | 840.0 | 818.4 | 778.1 |
| New Brunswick, 1926 | 51.0 | 458.8 | 597.0 | 889.7 | 861.8 |

The average conditions for growth were about the same for all three years, the deficiencies in one factor being largely counterbalanced by other favorable conditions. The average yield of tubers for all treatments was 149.8 bushels per acre in 1924, 143.6 bushels in 1925, and 149.1 bushels in 1926, indicating that the three sets of conditions were fairly comparable.

## EXPERIMENTAL DATA

The effect of size of seed piece and rate of planting on yield of tubers under the conditions outlined above is given in Table 2. The probable error of the experiment was calculated for each year by

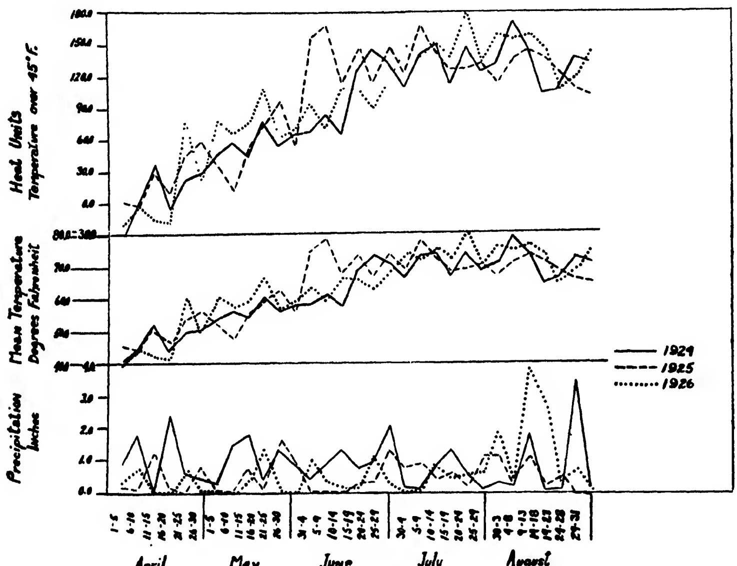


FIG. 1.—Precipitation, mean temperature, and heat units by five-day periods from April to August, inclusive, for 1924, 1925, and 1926.

means of the method proposed by Student (4). As expressed in Table 2, the probable errors in per cent represent the errors of any treatment made up of duplicate plats in 1924 and triplicate plats in the other years. The probable error of each treatment may be expressed in bushels by multiplying the probable error in per cent with the yield.

It is apparent that increased quantities of seed per acre have increased total yields of tubers with all three sizes of seed piece. Moreover, this has been true even though the quantities of seed used were as great as 33.0 bushels per acre. The seed piece used by farmers in central New Jersey at present averages slightly smaller than 1

TABLE 2.—*Effect of size of seed piece and rate of planting on yield of Green Mountain potatoes in central New Jersey, 1924–26, inclusive.*

| Treatment | Size of seed piece, ounce | Spacing of plants in the row, inches | Seed used per acre, bushels | Total yield in bushels per acre | | | Average total yield | | Total yield minus seed in bushels | Total yield minus 2 times bushels of seed in bushels | Total yield of tubers per bushel of seed in bushels |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Farmingdale, 1924 | Jamesburg, 1925 | New Brunswick, 1926 | Bushels | Per cent | | | |
| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) (9) | (10) | (11) | (12) | (13) |
| A | ½ | 12 | 8.25 | 133.3 | 100.4 | 109.3 | 114.3±4.06 | 60.7 | 106.0 | 89.5 | 13.9 |
| B | ½ | 9 | 11.00 | 159.9 | 147.4 | 134.1 | 147.1±5.22 | 78.1 | 136.1 | 125.1 | 13.4 |
| D | ½ | 7½ | 13.20 | 144.5 | 143.9 | 144.2 | 144.2±5.12 | 76.5 | 131.0 | 117.8 | 10.9 |
| G | ½ | 6 | 16.50 | 160.9 | 148.0 | 192.8 | 167.2±5.94 | 88.7 | 150.7 | 134.2 | 10.1 |
| C | 1 | 18 | 11.00 | 126.1 | 123.8 | 122.1 | 124.0±4.40 | 65.8 | 113.0 | 102.0 | 11.3 |
| E | 1 | 15 | 13.20 | 153.7 | 150.1 | 132.5 | 145.4±5.16 | 77.2 | 132.2 | 119.0 | 11.0 |
| H | 1 | 12 | 16.50 | 154.8 | 153.9 | 159.7 | 156.1±5.54 | 82.9 | 139.6 | 123.1 | 9.5 |
| J | 1 | 9 | 22.00 | 166.5 | 154.8 | 182.8 | 168.0±5.96 | 89.2 | 146.0 | 124.0 | 7.6 |
| F | 1½ | 22½ | 13.20 | 123.0 | 120.5 | 119.1 | 120.9±4.29 | 64.2 | 107.7 | 94.5 | 9.2 |
| I | 1½ | 18 | 16.50 | 129.1 | 142.0 | 129.5 | 133.5±4.74 | 70.9 | 117.0 | 100.5 | 8.1 |
| K | 1½ | 13½ | 22.00 | 148.6 | 173.0 | 161.8 | 161.1±5.72 | 85.5 | 139.1 | 117.1 | 7.3 |
| L | 1½ | 9 | 33.00 | 197.8 | 165.6 | 201.8 | 188.4±6.69 | 100.0 | 155.4 | 122.4 | 5.7 |
| Average yield for all treatments | | | | 149.8 | 143.6 | 149.1 | 147.5±5.24 | | | | |
| Probable error of the experiment, % | | | | 6.21 | 7.75 | 3.89 | 3.55 | | | | |

ounce, and approximately 14 bushels of seed are used per acre (1). If the same size of seed piece is retained, it would seem desirable from these tests to increase the amount of seed per acre by spacing plants closer in the row. On the other hand, increasing the size of seed piece and maintaining the same spacing has been very effective in increasing total yields in these tests.

The reason why higher yields of tubers are obtained when seed pieces are spaced closer in the row is not clear from these tests since no investigations of root systems were made. It is possible that the increase in yield is related to the moisture supply. Roots of potato plants may reasonably be expected to extend at least 1 foot on either side of the central stem (5), so that all surface layers of soil should be utilized for moisture even at the widest spacings. However, if the vertical penetration of the roots is increased by closer spacing, then greater volumes of soil would be occupied, and consequently a greater total amount of water would be made available for use by the crop during critical periods in July and August.

Closer spacings of plants may also result in more thorough utilization of the fertilizer added and thus account for increased yields. The common practice in central New Jersey is to apply 1,500 to 2,000 pounds of fertilizer in the row beneath the seed piece at planting time. With this type of fertilizer distribution, the greater quantities of roots formed near the row by closely spaced plants may result in more effective utilization of the nutrients and higher yields. The amounts of fertilizer used have been profitable, but the residual effect has been very marked, indicating that much of the material has not been used by the potato crop. Closer spacings may merely mean a greater number of intimate contacts between roots or roothairs and the undissolved mineral nutrients and the absorption of nutrients which would otherwise be left unsued. If closer spacing of seed pieces causes a greater development of roots in the lower soil horizons, it seems likely that much soluble fertilizer would be available for absorption that would otherwise be leached beyond the reach of the roots.

There is no doubt that small seed pieces give greater yields than large ones when equal total weights of seed are used per acre. Thus 11 bushels of 1-ounce pieces produced a yield of 124.0 bushels per acre, while the same weight of ½-ounce seed pieces produced 147.1 bushels. Similar relations may be observed when all three sizes of seed pieces were planted at the rate of 13.2 bushels per acre (compare treatments D, E, and F), at the rate of 16.5 bushels (treatments G, H, and I), and at the rate of 22.0 bushels per acre (treatments J and K).

It seems unlikely that the increase in yield from smaller seed pieces is due to any inherent superiority in the size of seed piece itself. Small pieces are more apt to suffer from desiccation than large ones because of the relatively greater surface area exposed. Small seed pieces may also absorb moisture more readily than larger ones due to the greater surface area exposed, but since moisture was adequate at planting time in these tests it is doubtful if this was a contributing factor to the larger acre yields resulting from smaller pieces.

Small seed pieces also have smaller quantities of reserve food than large pieces and the young plants are forced to manufacture all of their food at an earlier date than would otherwise be necessary. Young plants from small seed pieces are less vigorous than those from large pieces if the number of stems produced per plant may be used as an indication. In 1924, the average number of stems per seed piece was 1.25, 1.53, and 2.02 for the ½-ounce, 1-ounce, and 1½-ounce seed pieces, respectively.

Stuart, et al (3), has reported that the number of stems per seed piece increased as the weight increased, but whether this was due to the greater supply of reserve food at hand or merely to the greater number of eyes occurring on heavier seed pieces is not clear. Other investigations (reviewed by Stuart) indicate that a part at least of the increased number of stems was due to the increase in number of eyes, but that much of the increase was due to the weight of the seed piece.

From an economic standpoint it is essential to determine the total yield of tubers minus the amount of seed used. This information is given in column 11 of Table 2. It will be noted that these net yields are still the highest for the heaviest rates of planting, even though the differences in yield between heavy and light rates are not as great as those noted in column 8. Small seed pieces are also more profitable than large ones when all are planted at equal weights per acre.

The most productive combination of size of seed piece and rate of planting was a 1½-ounce piece spaced 9 inches in the row and requiring 33 bushels of seed per acre. However, 1-ounce pieces spaced 9 inches in the row and ½-ounce pieces spaced 6 inches in the row were nearly as productive. In years when the cost of seed is high as compared with the selling price of the crop, the ½-ounce pieces spaced 6 inches in the row should be the most profitable of any combination tested in these experiments (Table 2, column 12).

There is one practical difficulty involved in the use of ½-ounce seed pieces that should be kept in mind. With large size seed tubers, there may be considerable waste if the eyes are not numerous. Par-

ticularly when machine cutting is practiced, cutting ½-ounce pieces may result in many pieces with no eyes, which would be almost a total loss. From the practical standpoint, it would probably be better to cut larger sized pieces where necessary, in order to have at least one eye per piece, with the same spacing of pieces in the row.

Occasionally the producer of high quality seed or the plant breeder wishes to know what spacing and size of seed piece will give the greatest returns per bushel of seed. From these experiments (Table 2, column 13) it seems clear that ½-ounce seed pieces spaced at least 12 inches apart in the row permitted the greatest total yield from a given quantity of seed.

The yield of marketable tubers per acre hold more significance for the producer of potatoes than total yields. The 100 representative hills harvested from each treatment in 1925 and 1926 were used to note the effect of size of seed piece and rate of planting on the percentage by weight per hill of tubers weighing over 45 grams each, and the average number and weight of such tubers per hill. These results are shown in Table 3.

In 1925 the various treatments had little or no effect on the percentage of marketable tubers (over 45 grams) produced, but in 1926 the percentage varied from 81.3 to 89.5. Since the percentages show no correlation with either size of seed piece or rate of planting, no special significance should be attached to the variations occurring in 1926. From these data it seems safe to assume that all treatments were equal in their effect on percentages of marketable stock produced. The preceding discussion of total yields, and of total yields minus seed, therefore, applies equally well to yields of marketable tubers.

It is of interest to know whether yields of marketable tubers rise and fall because of changes in the number of tubers, or changes in their weight, or both. In these tests, it was found that more marketable tubers were produced per hill by large seed pieces than small ones when both were spaced at the same distances in the row. This difference in number of marketable tubers per hill accounts in large measure for the differences noted in yields per acre. The large seed undoubtedly produced stronger plants and set more tubers than small seed pieces because of the more abundant supplies of reserve food in the seed piece.

There was a well-defined tendency for the number of marketable tubers per hill to increase as the space between plants increased. This is readily explained on the basis of the greater amount of moisture and nutrients available per plant at the wider spacings.

TABLE 3.—*Effect of size of seed piece and rate of planting on the percentage by weight, the average number, and weight of marketable tubers per hill for 1925 and 1926.*

| Treatment | Size of seed piece, ounce | Spacing of plants in the row, inches | Seed used per acre, bushels | Percentage by weight of total yield comprised of tubers weighing over 45 grams each | | | Average number of tubers per hill weighing over 45 grams each | | | Average weight per tuber of those weighing over 45 grams each in grams | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 1925 | 1926 | Average | 1925 | 1926 | Average | 1925 | 1926 | Average |
| A | ½ | 12 | 8.25 | 93.6 | 88.2 | 90.9 | 2.0 | 1.9 | 1.95 | 112 | 103 | 107 |
| B | ½ | 9 | 11.00 | 95.4 | 86.3 | 90.8 | 2.7 | 2.4 | 2.55 | 110 | 104 | 107 |
| D | ½ | 7½ | 13.20 | 95.3 | 85.6 | 90.4 | 2.1 | 2.0 | 2.05 | 121 | 98 | 109 |
| G | ½ | 6 | 16.50 | 94.7 | 84.6 | 89.6 | 1.9 | 2.1 | 2.00 | 115 | 97 | 106 |
| C | 1 | 18 | 11.00 | 95.3 | 88.6 | 91.9 | 3.0 | 3.1 | 3.05 | 121 | 113 | 117 |
| E | 1 | 15 | 13.20 | 97.8 | 89.5 | 93.6 | 3.0 | 2.9 | 2.95 | 130 | 101 | 115 |
| H | 1 | 12 | 16.50 | 96.2 | 86.0 | 91.1 | 2.7 | 2.7 | 2.70 | 123 | 105 | 114 |
| J | 1 | 9 | 22.00 | 93.5 | 81.3 | 87.4 | 2.4 | 2.3 | 2.35 | 110 | 96 | 103 |
| F | 1½ | 22½ | 13.20 | 95.9 | 86.9 | 91.4 | 3.5 | 2.7 | 3.10 | 131 | 100 | 115 |
| I | 1½ | 18 | 16.50 | 95.3 | 85.1 | 90.2 | 3.2 | 3.1 | 3.15 | 120 | 96 | 108 |
| K | 1½ | 13½ | 22.00 | 95.8 | 84.2 | 90.0 | 3.1 | 3.0 | 3.05 | 124 | 101 | 112 |
| L | 1½ | 9 | 33.00 | 95.6 | 86.9 | 91.2 | 2.8 | 3.1 | 2.95 | 108 | 99 | 103 |
| Average for all treatments | | | | 95.4 | 86.1 | 90.7 | 2.7 | 2.6 | 2.65 | 119 | 101 | 110 |

Frequent mention may be found in reports of experiments on size of seed piece that the size of the individual tubers is greatly affected both by the weight of the seed piece and the spacing in the row. The results reported in Table 3 fail to show any considerable effect of either factor on the average weight of marketable tubers produced. The average weight per tuber was somewhat lower in 1926 on the silt loam than in 1925 on the sandy loam but no other distinct trends may be noted. The slight inferiority of the ½-ounce seed pieces in weight of tubers produced was not sufficiently pronounced to be of significance. It is apparent, therefore, that changes in yields have been effected primarily through the number of tubers produced per hill.

## SUMMARY

1. Tests with certified Green Mountain potatoes under central New Jersey conditions covering a period of three years indicate that yields may be greatly changed both by the size of the seed piece and the spacing in the row.

2. Reducing the space between seed pieces of the same size has increased yields, presumably because the heavier planting has permitted more effective utilization of soil moisture and nutrients.

3. Increasing the size of seed piece greatly increased yields when the spacing in the row remained the same, even though this required as much as 33.0 bushels of seed per acre.

4. When the total weight of seed used per acre remained constant, the highest yields were obtained from ½-ounce seed pieces and the lowest from 1½-ounce pieces, with 1-ounce seed pieces occupying an intermediate position.

5. When the amount of seed used per acre is subtracted from total yields, the net yields have increased with the rate of planting for each size of seed piece.

6. If the cost of seed had been relatively high as compared with the price received for the crop, ½-ounce seed pieces planted at the rate of 16.5 bushels per acre would have been more profitable than any other treatment included in this test. This is based on the assumption that ½-ounce seed pieces may be cut with as little waste as larger sizes.

7. The greatest returns of crop per bushel of seed were obtained from ½-ounce pieces spaced 12 inches apart in the row.

8. Size of seed piece and rate of planting had no appreciable effect on the percentage (by weight) of tubers weighing over 45 grams each.

9. Variations in yield were caused primarily by changes in the number of tubers weighing over 45 grams each and not by their average individual weight.

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# THE EFFECT OF NARROW ALLEYS ON SMALL GRAIN YIELDS[1]

C. K. McCLELLAND[2]

It has long been proved that the outer drill rows bordering on unplanted alleys will yield more than the inner drill rows. The effect on the plat yield is dependent on a number of factors including size and shape of plat and the width or area of the dividing strip, and the management of this whether it be in sod, in crop, cultivated, or simply unplanted.

Barber[3] showed the percentage of total area in a 6-inch border in different sizes and shapes of plats. He stated that on square plats 1/30 acre in area, the yields are about 106.7% of the true yield; on 1/100 acre plats, 109% of the true yield; and on 1/1000 acre plats, the yield will be 128% of the true yield because of the higher yields of border plants. These percentages would be higher in long narrow plats where the percentage in border increases rapidly.

Arny and Hayes[4] studied the subject of alley effect under three heads, *viz.*, (a) How far within plats is alley effect operative? (b) What is the increase in yield due to alley effect? and (c) In plats surrounded by alleys, is the effect of the additional space the same on all varieties?

They show that with 18-inch alleys, when outside border rows only are considered, the yields of wheat, oats, and barley are excessively high and that even the second or inside border rows give yields higher than those obtained from the 13 central rows.

They found that cereals, particularly oats and barley, grown on the outer rows of the plat were later and heavier than from central rows and from their results they conclude that border effect is felt at least 12 inches from the alleys. Tables are presented similar to those of Barber but giving percentages of total area of a 12-inch border in different sizes and shapes of plats. The borders at sides of plats are considered as well as for sides and ends combined. They also show how the ranking of varieties is different when the border rows have been eliminated, due to the fact that the alleys have affected their various yields unequally. They conclude that the removal of two border rows is necessary to eliminate border effect and competition.

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[3]BARBER, E. W. Note on the influence of shape and size of plots in tests of varieties of grain. Me. Agr. Exp. Sta. Bul. 226:76–84. 1914.

[4]ARNY, A. C., and HAYES, H. K. Experiments in field technic in plot tests. our. Agr. Res., 15:251–262. 1918.

Kiesselbach[5] in discussing border rows and uncropped alleys between plats suggests reducing the alley to a minimum and then harvesting borders and all, but admits, "that experimental data bearing upon this are insufficient and more should be obtained." Since this practice has been followed at the Arkansas Experiment Station, a study of the results may be of interest to agronomists elsewhere.

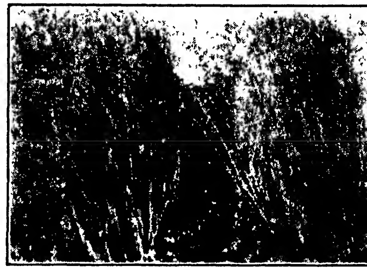

FIG. 1.—Growth of clover in a narrow alley.

## OTHER FACTORS INVOLVED

It seems to the writer that two other factors than those listed above enter into the problem. These are (a) whether the alley is cropped in another crop (as clover), whether it is uncropped, or whether it is cultivated; and (b) whether the area of the alley is considered in determining the plat and acre yields. (See also Kiesselbach, *loc. cit.*)

In this paper, however, the latter point is discussed more fully since no data on the former are now available. At the Arkansas Experiment Station clover is seeded over all the small grain fields, whether fall or spring sown. The growth of the clover in the narrow alleys (16-inch gross) is greater than between the drills (8-inch). (See Figs. 1 and 2.) It must therefore exercise some influence in reducing border effect and also competition. So true is this that the border effect as shown to the eye by taller and later plants is barely noticeable. In 1926, however, because of partial failure of the clover, border effect was more marked and this led to the harvesting of rod rows from several plats for the purpose of studying the relative yields of the various rows. This was done with both winter wheat and winter oats. In 1928, similar work with spring oats was done. Table 1 shows yields in grams from the separate rod rows, while Table 2 gives conversion factors used in computing the acre-yields, and the average yields from each crop computed in different ways. Also, by letters, the disturbance or change in rank on account of including the border rows and alley is shown.

These results are not from a planned experiment with one variety, but from plats of different varieties and no recognition is made of any competition which may exist. In the case of the oats some of the

[5]KIESSELBACH, T. A. The mechanical procedure of field experimentation Jour. Amer. Soc. Agron., 20:433-442. 1928.

TABLE 1.—*Relative yield from the different rows of an eight-disc drill (8 inches apart) and with 15–16 inch alley.*

| Weights in grams from rod-rows | | | | | | | | Total six inner rows | Total eight rows | Yield from six rows | Yield from eight rows and alley |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Row-1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | | | | |
| Winter oats, 1926 | | | | | | | | | | | |
| 155 | 145 | 190 | 145 | 145 | 160 | 260 | 145 | 1,045 | 1,345 | 47.55a | 40.75b |
| 215 | 165 | 125 | 160 | 145 | 145 | 165 | 265 | 905 | 1,385 | 41.18b | 41.97a |
| 105 | 175 | 155 | 145 | 95 | 120 | 125 | 200 | 815 | 1,120 | 37.08c | 33.94e |
| 205 | 140 | 130 | 142 | 110 | 75 | 210 | 162 | 807 | 1,174 | 36.72d | 35.57c |
| 185 | 160 | 130 | 130 | 125 | 80 | 150 | 149 | 775 | 1,109 | 35.26e | 33.60h |
| 175 | 130 | 180 | 180 | 80 | 130 | 60 | 180 | 760 | 1,115 | 34.58f | 33.78f |
| 210 | 165 | 105 | 115 | 120 | 115 | 115 | 185 | 735 | 1,130 | 33.44g | 34.23d |
| 165 | 150 | 145 | 88 | 100 | 135 | 105 | 140 | 723 | 1,028 | 32.90h | 31.15i |
| 135 | 155 | 95 | 145 | 85 | 140 | 95 | 170 | 715 | 1,020 | 32.53i | 30.91l |
| 245 | 110 | 70 | 95 | 120 | 180 | 115 | 175 | 690 | 1,110 | 31.40j | 33.63g |
| 110 | 145 | 115 | 115 | 80 | 165 | 60 | 165 | 680 | 955 | 30.94k | 28.94o |
| 150 | 85 | 115 | 80 | 110 | 163 | 125 | 165 | 678 | 993 | 30.85l | 30.09n |
| 150 | 115 | 85 | 95 | 110 | 100 | 173 | 70 | 678 | 898 | 30.85m | 27.21q |
| 190 | 105 | 140 | 115 | 85 | 95 | 135 | 150 | 675 | 1,015 | 30.71n | 30.75m |
| 170 | 138 | 130 | 102 | 155 | 48 | 90 | 195 | 663 | 1,028 | 30.17o | 31.15j |
| 95 | 135 | 130 | 120 | 80 | 85 | 75 | 120 | 625 | 840 | 28.43p | 25.45s |
| 200 | 140 | 130 | 120 | 95 | 85 | 50 | 205 | 620 | 1,025 | 28.21q | 31.06k |
| 150 | 95 | 90 | 105 | 65 | 110 | 115 | 125 | 580 | 855 | 26.39r | 25.91r |
| 120 | 65 | 100 | 90 | 110 | 95 | 110 | 125 | 570 | 815 | 25.94s | 24.69t |
| 90 | 128 | 85 | 75 | 95 | 70 | 110 | 115 | 563 | 768 | 25.62t | 23.27u |
| 190 | 65 | 85 | 105 | 100 | 105 | 90 | 175 | 550 | 915 | 25.03u | 27.72p |
| 80 | 100 | 70 | 85 | 72 | 90 | 110 | 95 | 527 | 702 | 23.98v | 21.27w |
| 80 | 68 | 83 | 130 | 75 | 85 | 55 | 135 | 496 | 711 | 22.57w | 21.54v |
| 60 | 125 | 70 | 80 | 100 | 85 | 30 | 90 | 490 | 640 | 22.30x | 19.39x |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 25 | 110 | 70 | 35 | 105 | 30 | 65 | 80 | 415 | 520 | 18.88y | 15.76y |
| Total | | | | | | | | | | | |
| 3,655 | 3,114 | 2,823 | 2,797 | 2,562 | 2,691 | 2,793 | 3,781 | 16,780 | 24,216 | 763.51 | 733.73 |
| Average | | | | | | | | | | | |
| 146.20 | 124.56 | 112.92 | 111.88 | 102.48 | 107.64 | 111.72 | 151.24 | 671.2 | 968.64 | 30.54 | 29.35 |
| Bushels per acre | | | | | | | | | | | |
| 39.91 | 34.00 | 30.83 | 30.54 | 27.98 | 29.39 | 30.50 | 41.29 | | | | |
| Winter wheat, 1926 | | | | | | | | | | | |
| 325 | 200 | 255 | 275 | 290 | 235 | 190 | 330 | 1,445 | 2,100 | 35.11a | 34.02b |
| 392 | 220 | 215 | 265 | 310 | 322 | 80 | 380 | 1,412 | 2,184 | 34.31b | 35.38a |
| 260 | 210 | 220 | 250 | 250 | 215 | 200 | 130 | 1,345 | 1,735 | 32.68c | 28.11f |
| 230 | 230 | 245 | 195 | 270 | 165 | 210 | 335 | 1,315 | 1,880 | 31.95d | 30.46 |
| 240 | 150 | 250 | 235 | 240 | 210 | 225 | 328 | 1,310 | 1,878 | 31.83e | 30.42d |
| 285 | 190 | 130 | 260 | 285 | 155 | 190 | 390 | 1,210 | 1,885 | 29.40f | 30.54e |
| 285 | 175 | 150 | 195 | 245 | 175 | 150 | 250 | 1,090 | 1,625 | 26.49g | 26.33c |
| 245 | 145 | 190 | 253 | 215 | 180 | 95 | 195 | 1,078 | 1,518 | 26.20h | 24.59g |
| 290 | 150 | 145 | 160 | 260 | 200 | 155 | 250 | 1,070 | 1,610 | 26.00i | 26.08i |
| 205 | 185 | 110 | 220 | 180 | 220 | 125 | 150 | 1,040 | 1,395 | 25.27j | 22.60jh |
| Total | | | | | | | | | | | |
| 2,757 | 1,855 | 1,910 | 2,308 | 2,545 | 2,077 | 1,620 | 2,738 | 12,315 | 17,810 | 299.24 | 288.53 |
| Average | | | | | | | | | | | |
| 275.7 | 185.5 | 191.0 | 230.8 | 254.5 | 207.7 | 162.0 | 273.8 | 1,231.5 | 1,781.0 | 29.92 | 28.85 |
| Bushels per acre | | | | | | | | | | | |
| 39.98 | 26.90 | 27.7 | 33.47 | 36.9 | 30.12 | 23.49 | 39.7 | | | | |

TABLE 1—*Concluded.*

| Weight in grams from rod-rows | | | | | | | | Total six inner rows | Total eight rows | Yield from six rows | Yield from eight rows and alley |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Row 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | | | | |
| Spring oats, 1928 | | | | | | | | | | | |
| 260 | 190 | 220 | 180 | 190 | 260 | 190 | 240 | 1,230 | 1,730 | 55.97a | 52.42a |
| 260 | 210 | 200 | 170 | 200 | 220 | 170 | 240 | 1,170 | 1,670 | 53.24b | 50.60b |
| 260 | 220 | 170 | 210 | 140 | 200 | 200 | 260 | 1,140 | 1,660 | 51.87c | 50.30d |
| 280 | 210 | 200 | 160 | 180 | 170 | 210 | 260 | 1,130 | 1,670 | 51.42d | 50.60c |
| 250 | 230 | 150 | 190 | 170 | 190 | 200 | 220 | 1,130 | 1,600 | 51.42e | 48.48f |
| 250 | 180 | 210 | 170 | 200 | 170 | 190 | 260 | 1,120 | 1,630 | 50.96f | 49.39e |
| 230 | 180 | 190 | 160 | 140 | 250 | 190 | 220 | 1,110 | 1,560 | 50.51g | 47.27h |
| 210 | 170 | 180 | 220 | 150 | 220 | 170 | 210 | 1,110 | 1,530 | 50.51h | 46.36j |
| 200 | 180 | 220 | 150 | 170 | 160 | 200 | 270 | 1,080 | 1,550 | 49.14i | 46.97i |
| 300 | 170 | 180 | 150 | 160 | 220 | 190 | 220 | 1,070 | 1,590 | 48.69j | 48.18g |
| 220 | 140 | 160 | 200 | 160 | 200 | 210 | 240 | 1,070 | 1,530 | 48.69k | 46.36k |
| 200 | 180 | 150 | 200 | 120 | 200 | 200 | 270 | 1,050 | 1,520 | 47.78l | 46.06l |
| 230 | 170 | 190 | 150 | 190 | 180 | 160 | 210 | 1,040 | 1,480 | 47.32m | 44.84m |
| 270 | 180 | 170 | 160 | 160 | 200 | 170 | 100 | 1,040 | 1,410 | 47.32n | 42.72p |
| 200 | 170 | 160 | 140 | 160 | 190 | 190 | 200 | 1,010 | 1,410 | 45.96o | 42.72o |
| 270 | 180 | 190 | 140 | 170 | 170 | 140 | 210 | 990 | 1,470 | 45.05p | 44.54n |
| 190 | 200 | 180 | 120 | 170 | 180 | 130 | 220 | 980 | 1,390 | 44.59q | 42.12q |
| 160 | 150 | 180 | 150 | 130 | 210 | 160 | 180 | 980 | 1,320 | 44.59r | 40.00s |
| 210 | 120 | 130 | 160 | 140 | 210 | 160 | 240 | 920 | 1,370 | 41.86s | 41.51r |
| 200 | 150 | 180 | 100 | 170 | 140 | 120 | 160 | 860 | 1,220 | 39.13t | 36.97v |
| 180 | 150 | 180 | 120 | 120 | 140 | 140 | 200 | 850 | 1,230 | 38.68u | 37.27u |
| 210 | 140 | 150 | 100 | 150 | 150 | 150 | 200 | 840 | 1,250 | 38.22v | 37.88t |
| 200 | 150 | 140 | 140 | 120 | 170 | 110 | 160 | 830 | 1,190 | 37.77w | 36.06w |
| 220 | 160 | 160 | 130 | 120 | 110 | 110 | 160 | 790 | 1,170 | 35.95x | 35.45x |
| 150 | 140 | 80 | 110 | 150 | 160 | 110 | 160 | 750 | 1,060 | 34.13y | 32.12z |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 180 | 120 | 120 | 130 | 100 | 130 | 140 | 190 | 740 | 1,110 | 33.67z | 33.63y |
| 80 | 100 | 80 | 130 | 60 | 120 | 80 | 120 | 570 | 770 | 25.94 | 23.33 |
| Total | | | | | | | | | | | |
| 5,870 | 4,540 | 4,520 | 4,140 | 4,090 | 4,920 | 4,390 | 5,620 | 26,600 | 38,090 | 1,210.38 | 1,154.15 |
| Average | | | | | | | | | | | |
| 217.4 | 168.1 | 167.4 | 153.3 | 151.4 | 182.2 | 162.2 | 208.1 | 985.18 | 1,410.74 | 44.83 | 42.75 |
| Bushels per acre | | | | | | | | | | | |
| 59.35 | 45.89 | 45.7 | 41.85 | 41.33 | 49.74 | 44.39 | 56.81 | | | | |

TABLE 2.—*Summary of results.*

| | | Winter oats, 1926 | Winter wheat, 1926 | Spring oats, 1928 |
|---|---|---|---|---|
| Bushels per acre from all rows (8 x 8 inch width) | = | 33.06 | 32.28 | 48.13 |
| Bushels per acre from 2 outer rows (2 x 8 inch) | = | 40.60 ± 8.19 | 39.84 ± 11.98 | 58.08 ± 6.92 |
| Bushels per acre from 2 inner rows (2 x 8 inch) | = | 29.26 ± 3.62 | 35.19 ± 5.54 | 41.59 ± 4.42 |
| Bushels per acre from 4 inner rows (4 x 8 inch) | = | 29.69 | 32.05 | 44.66 |
| Bushels per acre from 6 inner rows (6 x 8 inch) | = | 30.54 ± 4.17 | 29.92 ± 2.51 | 44.82 ± 4.77 |
| Gain, 8 over 4 inner rows | = | 11.3% | 0.7% | 7.8% |
| Gain, 8 over 6 inner rows | = | 8.3% | 8.5% | 7.4% |
| Gain, 2 outer over 6 inner rows | = | 32.9% | 33.9% | 29.7% |
| Bushels per acre from all rows (72-inch instead of 64-inch width) | = | 29.35 ± 4.15 | 28.85 ± 2.75 | 42.75 ± 4.55 |
| Gain or loss as compared with 6 inner rows | = | —3.9% | —3.1% | —4.6% |

Conversion factors:—

| *Wheat* | *Oats* |
|---|---|
| Factor for 1 row 8 inches x 16.5 feet = grams x 0.1457 | Factor for 1 row 8 inches x 16.5 feet = grams x 0.273 |
| Factor for 6 rows 8 inches x 16.5 feet = grams x 0.0243 | Factor for 6 rows 8 inches x 16.5 feet = grams x 0.0455 |
| Factor for 8 rows 8 inches x 16.5 feet = grams x 0.0182 | Factor for 8 rows 8 inches x 16.5 feet = grams x 0.0341 |
| Factor for 8 rows 8 inches x 16.5 feet + 8 inches alley = grams x 0.0162 | Factor for 8 rows 8 inches x 16.5 feet + 8 inches alley = grams x 0.0303 |

plats, but not all, are adjacent. In the case of the wheat all are adjacent. Also, with the spring oats there is some duplication of varieties, the plats being harvested from third and fourth series of a general variety test. Later, perhaps, a more thorough study by harvesting from all four series can be made but here no recognition is made of the duplicates. The basis of selection was proper stage for cutting on a day when it was most convenient for doing the work and neither the earliest nor latest varieties are included. While the plans are open to much criticism, the harmony of the results obtained testify to the more or less "random" nature of the choice of plats.

FIG. 2.—Growth of clover in several alleys in a wheat field.

Since the data are from different varieties, it has not been thought worth while to determine measures of variation for all results. The coefficients of variation for the acre yields in the last two columns may be considered as a measure of competition since competition in the border rows should increase variability. These coefficients are as follows:

| | Winter oats % | Winter wheats % | Spring oats % |
|---|---|---|---|
| From 6-row yields.................. | 20.22 | 12.43 | 15.78 |
| From 8-row and alley yields.......... | 20.96 | 14.10 | 15.79 |

They indicate some slight increase of variability in winter oats and a considerable amount in the winter wheat due to competition. The larger probable errors (Table 2) of the yields of the border rows considered alone may be interpreted also as an indication of competition along the alleys.

The correlation coefficients between the figures of the last two columns were found to be

In winter oats 1926............ r = + 0.938 ± .016
In winter wheat 1926........... r = + 0.955 ± .011
In spring oats 1928............. r = + 0.934 ± .027

Such high correlation, and odds, as indicated by the smallness of the probable errors indicate that one system of obtaining the results is about as exact as the other. The differences are as follows:

| | Winter oats | Winter wheat | Spring oats |
|---|---|---|---|
| Yields from 6 inner rows | 30.54 ± 4.17 | 29.92 ± 2.51 | 44.82 ± 4.77 |
| Yields from 8 rows plus alley | 29.35 ± 4.15 | 28.85 ± 2.75 | 42.75 ± 4.55 |
| Difference | 1.19 ± 5.88 | 1.07 ± 3.72 | 2.07 ± 6.59 |

Since probable errors of differences are from three to five times as large as the differences themselves, it may be concluded from these results also that one method is about as exact as the other.

The drill used is an eight-disc drill which is approximately 72 inches wheel to wheel or 8 inches between discs. The full plats then are 1/55 acre (6 feet x 132 feet), or without alley, 1/60 acre (5.5 feet x 132 feet) approximately. The grain at the ends of the plats is cut with a mowing machine just before harvesting with a binder. Table 2 shows increases of two outside rows over six central rows to be 32.9%, 33.9%, and 29.7% which is quite consistent. The gain of the full eight rows over the six central rows is 8.3%, 8.5%, and 7.4% which is again quite consistent, and agrees with Barber's results for square plats in being intermediate between the increases for 1/50 and 1/100 acre in area. The gain of the eight rows over the four central, however, varied from 0.7% with the wheat to 11.3% with the winter oats. Average results show no alley effect on "inner border" rows, although with the winter oats (Table 1) some slight effect is indicated.

However, if the "net" width of the alley be included in the plat area, the yields of all eight are found to be —3.9%, —3.1%, and —4.6% as compared with the yield from the six central rows. This suggests that there might be a definite relation between width of drill, i.e., planted area, and width of alley in which there is proper compensation—the increased yield of the border rows being balanced by the increase in area obtained by including the alley.

## DISTURBANCE IN RANK

In the case of the winter oats it will be noted from the rearrangement of the letters in the last column that of the first 10 in rank in the preceding column, 9 are found in high place in the last column. Also, that of the last 10, 9 are found in last place in the rearrange-

ment, though there is some shifting. In the case of the wheat, the six highest varieties and the four lowest are the same in both of the ranked columns. In the case of the spring oats, the 10 highest under one plan hold their position under the other, while the last 10, or 11, are the same under either plan. This indicates no great shifting of rank and no injustice to any variety since each holds its place as high, medium, or low-yielding and the slight shifts from what some would term the "true rank" will be taken care of in the average of several years' trials. The variation in yield by the different method of calculation is much less than seasonal variation of the varieties or even than plat variation in different replications.

If the net width of the alley in Arny and Hayes[6] tests be used, we shall find a somewhat similar and close agreement in results. In these the net width of alley is 12 inches or 2 drills. Multiplying the yields by their respective weights 2–2–13, summing, and dividing by 19, we may compare results with those obtained from the central rows as follows:

| Yields (bushels) from | Oats | Wheat | Barley |
|---|---|---|---|
| 13 central rows | 71.37 | 27.45 | 42.87 |
| Total weighted results ÷ 19 | 71.98 | 28.88 | 46.4 |
| 15 central rows | 73.58 | 29.25 | 45.75 |
| Gain or loss of entire plat: | | | |
| Over 13 central rows | + 0.85% | + 5.21% | + 8.23% |
| Over 15 central rows | — 2.17% | — 1.27% | + 1.42% |

The agreement is close in either case but apparently nearer to the results obtained from the 15 central rows. That these are always larger than from the 13 central rows is an indication of too great width in the alley which contributes to an excessive border effect. Even the percentage variation which is open to wide fluctuation is small in the majority of cases.

When the drill wheel is returned across a section or range in its own track, we have about as narrow an alley as can be utilized. This permits space enough for the dividing board of a binder but none too much, and presupposes always that no grain will be blown dow or lodged from excessive fertility or overripeness. In some years there is no way in which to prevent mixing of varieties in the harvesting except by hand cutting the border rows, but our results would seem to indicate the possibility of getting the right plat-alley combination whereby this extra labor may generally be avoided. Kiesselbach (*loc. cit.*) states that plat borders (lateral only, of 900 plats) of the Nebraska Experiment Station plats are 72 miles in length. To avoid harvesting borders separately and by hand on any such number of plats is "a consummation devoutly to be wished."

[6]*Loc. cit.*

# CHEMICAL AND MICROBIOLOGICAL PRINCIPLES UNDERLYING THE TRANSFORMATION OF ORGANIC MATTER IN THE PREPARATION OF ARTIFICIAL MANURES[1]

SELMAN A. WAKSMAN, FLORENCE G. TENNEY, AND ROBERT A. DIEHM[2]

It has been shown repeatedly and it has long been known from practical experiments that the addition of straw to soil has a decided injurious effect upon the growth of the crop following. Various theories were suggested in which an attempt was made to explain this injurious action by the presence of toxic substances within the straw. These theories, however, were not supported by sufficient experimental evidence. Investigators generally agree now that this injurious effect of the application of mature straw upon the growing crop is due largely to a lack of available nitrogen in the soil.

Straw being rich in hemicelluloses and celluloses (comprising 60% of the total dry matter) represents an excellent source of energy for the soil micro-organisms. In the process of decomposing the straw these organisms synthesize considerable quantities of cell substance. For this purpose they require a definite amount of nitrogen which is transformed into proteins and other nitrogen complexes of the microbial cells. This nitrogen must be in an available combined form, such as nitrates and ammonium salts or as readily decomposable proteins, since the organisms attacking the celluloses are unable to use or "fix" atmospheric nitrogen. When no available nitrogen is added to the soil with the straw, the soil micro-organisms, largely fungi and aerobic bacteria which use the chemical complexes of the straw as sources of energy, will consume all the available nitrogen in the soil for their own synthetic needs and thus compete for the soil nitrates with the higher plants. Hence, nitrogen starvation sets in in the soil, at least so far as the growth of the cultivated crop is concerned.

The injurious effect upon plant growth following the addition of straw to the soil is thus found to be due largely to a lack of sufficient available nitrogen (and phosphorus to a less extent) in the soil. This has been proved to be the case (a) by direct plant experimentation, (b) by laboratory investigations, and (c) by theoretical considerations of the metabolism of the soil organisms.

[1]Contribution from the Department of Soil Chemistry and Bacteriology, New Jersey Agricultural Experiment Station, New Brunswick, N. J. Received for publication February 9, 1929.

This is the second of a series of three papers dealing with the principles underlying the utilization of natural organic materials on the farm.

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Krüger and Schneidewind (10)[3] have shown long ago that when a crop of legumes is grown soon after the addition of straw to the soil no injurious effect is observed, due to the fact that, as a result of the symbiotic action with specific bacteria which form nodules on their roots, the legumes are independent of the supply of available nitrogen in the soil. When the soil is partially sterilized by the use of disinfectants or steam following the addition of straw thereby killing the fungi and cellulose decomposing bacteria, there is no injury from the straw even to non-leguminous plants. The process of partial sterilization of soil makes the celluloses of the straw practically inert as a source of energy, due to the elimination of the micro-organisms which decompose the celluloses; therefore, no lack of nitrogen will be experienced by the growing plant.

As a result of these considerations, it can be readily understood why the addition to the soil of available nitrogen with the straw was found to result in a practical nullification of this injurious effect. To illustrate this phenomenon further and to demonstrate definitely that the celluloses in the straw which are used by micro-organisms as sources of energy are responsible for the injury, it may be sufficient to call attention to the fact that when chemically pure celluloses are added to the soil the same injurious action upon plant growth is observed.

The idea of Koch (9) that celluloses are used indirectly as sources of energy by nitrogen-fixing bacteria and will thus bring about an increase in crop yield in the second and following crops, even i the first crop may show a depressing effect of the cellulose, was not substantiated (15). The total crop yields for a number of consecutive years on those soils which received the addition of cellulose and those that did not receive any such addition have not been to the advantage of the former. The depression suffered by the first crop in the soil receiving cellulose was followed by an increase in yield of the second crop due to the liberation of some of the nitrogen which has been stored away at first as a result of the decomposition of the synthesized microbial cell substance, but the second year's increase never balanced the first year's loss.

Careful studies of the decomposition of celluloses by pure and mixed cultures of micro-organisms (6) have brought out the fact that there is a direct correlation between the degree of decomposition of celluloses and the assimilation of inorganic nitrogen. There is no loss of any of the nitrogen, but merely its transformation from inorganic into organic forms. This leads to a temporary withdrawal

[3]Reference by number is to "Literature Cited," p. 545.

from circulation of the available nitrogen. But after the celluloses have decomposed, the microbial cells will themselves undergo decomposition and gradually the nitrogen will again be liberated in the form of ammonia which is rapidly changed in the soil to nitrate. The amount of nitrogen required for the decomposition of celluloses by micro-organisms depends upon the soil conditions, especially reaction and aeration. It is generally equivalent to about 1 part of nitrogen for every 30 to 40 parts of cellulose decomposed. If less nitrogen than the required amount is available, the celluloses will decompose more slowly and it will take longer before they will completely disappear, depending on the rapidity with which the nitrogen is becoming available.

A detailed consideration of the metabolism of the fungi and bacteria which bring about the decomposition of the straw tends to confirm these observations.

The fact that fresh and partly decomposed stable manures, which are frequently rich in undecomposed straw but which also contain large quantities of available nitrogen in the form of urea and ammonium carbonate, do not exert any injury upon plant growth and are even highly beneficial tends to confirm further the above interpretation.

As a result of both practical observations and theoretical considerations, the idea suggested itself that when large quantities of straw are available on the farm, they could first be composted with the addition of available nitrogen and other minerals, largely phosphorus, potassium, and calcium, in the presence of sufficient water, and then applied to the soil in the form of a compost. This compost of so-called "artificial manure" should be equivalent in its fertilizing effect upon crops to that of composted stable manure. This was actually found to be the case in numerous field, greenhouse, and laboratory experiments as shown in various contributions to this subject.

Lemmermann (11) and Rahn (14) have found, for example, that when straw was composted without additional inorganic nitrogen there was a loss in four weeks of 9.0% of its dry material; when composted with 0.15% of nitrogen, the loss was 14.0 to 16.4%; and when composted with 0.30% nitrogen, the loss increased to 16.9 to 20.5% of its dry weight. The limited reduction in the bulk of the straw when no additional nutrients were added is due both to the decomposition of the water-soluble carbohydrates, this process being independent of the supply of available nitrogen in the soil since it can be carried out by the nitrogen-fixing bacteria, and to the presence

of small amounts of protein in the straw. The more considerable decomposition of the straw which took place in the presence of inorganic nitrogen compounds was no doubt due to the attack by the micro-organisms on the more complex polysaccharides, as shown later. The nature of the available nitrogen, as well as the presence or absence of $CaCO_3$, will influence the composition and, therefore, the nature of the material resulting from the decomposition.

Hutchinson and Richards (7) employed for every 100 parts of straw 0.7 part of nitrogen and found that urea and ammonium carbonate are the most appropriate sources of nitrogen for this purpose. Cyanamide could also be used, while ammonium sulfate proved efficient only in the presence of additional $CaCO_3$. Lemmermann and Gerdum (11) found that the addition of 600 liters of water containing 4 kgm of urea to 250 kgm of straw (moisture content of mixture 70%) gave a favorable amount of organic matter decomposition in three months under pressure of 70 kgm per square meter. The product thus obtained was similar to composted stable manure both chemically and physically as well as in its action upon plant growth. The artificial manure prepared from straw contained 20.5 to 26.3% dry matter, 0.43 to 0.44% nitrogen, 15.0 to 19.4% organic matter, and a carbon-nitrogen ratio of 17:1 to 22:1. The analysis of ordinary stable manure, on a similar basis, gave 20.3 to 23.0% dry matter, 0.46 to 0.55% nitrogen, 15.0 to 17.0% organic matter, and a C/N ratio of 15:1 to 16:1.

According to Prescott and Piper (12), straw mixed with the necessary chemicals and kept moist can be converted in about six months into an artificial manure which, at the rate of 40 tons per acre, gives practically the same results on potatoes as ordinary stable manure.

Halversen and Torgesson (5) used 0.5 to 0.75% nitrogen in the form of ammonium sulfate, together with sufficient lime to keep the reaction neutral. Six and a half months incubation outdoors, starting about the middle of March, resulted in a fine manure at a cost of 80 cents per ton of wet material.

Albrecht (1) suggested the use of a mixture of 45% ammonium sulfate, 40% finely ground limestone, and 15% superphosphate to be applied at the rate of 150 pounds per ton of straw. This results in the formation of a very good manure. Three tons of the product were obtained for each ton of straw at a cost of 85 cents per ton.

Collison and Conn (2) employed a mixture of 60 pounds of ammonium sulfate, 30 pounds superphosphate, 25 pounds of KCl, and 50 pounds of ground lime-stone to each ton of dry straw. When kept properly moistened, this mixture resulted in three to four months in a good grade of about 2 to 3 tons of artificial manure.

The need of available nitrogen, and to a less extent of phosphorus, calcium, and potassium, for a rapid decomposition of straw and other nitrogen-poor plant residues has thus been amply demonstrated. Furthermore, this nitrogen must be in a certain definite proportion to the organic matter used for the preparation of the compost. In the process of decomposition of the various constituents of the straw or other plant refuse by the micro-organisms, the nitrogen is rapidly transformed from an inorganic into an organic form. The amount of nitrogen required for the preparation of a proper compost will depend entirely upon the nature and age of the organic residue, or largely its nitrogen content. The nature of the non-nitrogenous organic constituents of the plant materials must also be taken into consideration, since the mere presence of additional inorganic fertilizing elements is not the only essential factor in the rapidity and extent of decomposition of the organic matter. Water-soluble substances, such as glucose, as shown above, are entirely independent of the presence of nitrogen, due to the fact that they can also be used as sources of energy by nitrogen-fixing bacteria. Other substances, such as lignins, undergo only very slow decomposition at best and no amount of available nitrogen will hasten the rapidity of their decomposition. The fact was established by Hébert (4) in 1892 that the lignin (vasculose) is most resistant to decomposition while chlorophyll substances and sugars are most readily decomposed. Dvorak (3) also found that young plants are decomposed more readily due to the greater abundance of sugars and of other lower carbohydrates, while older plants are more resistant to decomposition due to the abundance of ligno-celluloses. It has been demonstrated elsewhere (17) that not only do the lignins themselves not decompose readily, but their removal from the plant material hastens considerably the rapidity of decomposition of the celluloses.

These results lead to the conclusion that the rapidity of decomposition of plant substances by micro-organisms depends primarily upon two factors, *viz.*, (a) chemical composition of the plant as influenced by nature, age, soil conditions, etc.; and (b) the presence of available inorganic nutrients which will make possible the attack of the celluloses and hemicelluloses by the micro-organisms. The latter makes up usually the larger part of those plant materials which are commonly employed for the purpose of preparation of artificial manures and the major part (about 80 to 85%) of those fractions of the plant material which undergo rapid decomposition.

Rege (13) emphasized the importance of the pentosan fraction in the decomposition of mature plant materials by micro-organisms.

He distinguished between an energy factor, or readily available portion of the plant constituents which he identifies with the pentosans, and an inhibitory factor which he identifies with the lignins. This is hardly correct. The fact that pentosans decompose somewhat more rapidly than celluloses has been known for a long time. Jegorov (8) and others have demonstrated that in the composting of manure at 50% moisture there was a loss of 48.2% total dry matter, 82.6% pentosan, and 61.8% cellulose. In view of the fact, however, that the cellulose content of plant materials is usually considerably greater than the pentosan content, the total reduction in the actual amount of cellulose decomposed is greater than the amount of pentosan used up by the micro-organisms. As a result, the celluloses play a more important rôle than the pentosans in the total reduction in bulk of the decomposing organic matter and in the transformation of nitrogen from an inorganic into an organic form.

It is sufficient to cite here the following experiment dealing with the decomposition of mature rye straw (18). Twenty grams of straw receiving 100 mgm of nitrogen as di-ammonium phosphate and a small amount of di-potassium phosphate were composted for two months in the presence of an optimum amount of water (about 2 parts of water by weight to 1 part of dry matter).

TABLE 1.—*Decomposition of mature rye straw in two months.*

| Organic constituents | At beginning % | At end of decomposition % |
|---|---|---|
| Total water-insoluble organic matter | 100.0 | 58.03 |
| Pentosan | 26.0 | 10.3 |
| Cellulose | 41.5 | 18.3 |
| Lignin | 22.5 | 20.0 |
| Protein | 1.2 | 3.4 |

The results presented in Table 1 show that the lignins did not decompose readily and therefore accumulated in the compost. The pentosans and celluloses were reduced to less than a half of their original concentration in a period of two months. The decomposition of the pentosans was proportionally more rapid than that of the celluloses (8, 13), but quantitatively there was a loss of 23.2 parts of cellulose against 15.7 parts of pentosan. In other words, out of the 41.97 parts of the total dry organic matter decomposed, 23.2 parts, or 55.2%, was due to the decomposition of the celluloses and 15.7 parts, or 37.4%, to the decomposition of the pentosans, the decomposition of these two groups of plant constituents accounting for 92.6% of the organic matter lost. The proteins have increased markedly,

not only in proportion to the residual material in the compost, but also in actual total concentration. This is due to the transformation of some of the additional nitrogen from an inorganic into an organic form. These results are typical of what takes place in the process of preparation of artificial manure.

To bring out further the effect of nutrients upon the decomposition of the various constituents of the plant material, the following experiments (19) may be cited. The decomposition of mature rye straw and semi-mature corn stalks, in the presence and absence of additional inorganic nutrients (ammonium phosphate, potassium phosphate, and calcium carbonate), was studied under optimum moisture conditions in the laboratory. An analysis of the materials decomposed within a period of 28 days at 28°C gave the results brought out in Table 2.

TABLE 2.—*Decomposition of plant materials in the presence of additional inorganic nitrogen compounds and phosphates.*

| Organic matter in plant constituent | Rye straw | | | Corn stalks | | |
|---|---|---|---|---|---|---|
| | At start | At end of experiment: No nutrients | At end of experiment: Nutrients added | At start | At end of experiment: No nutrients | At end of experiment: Nutrients added |
| | % | % | % | % | % | % |
| Total dry organic matter | 100 | 93.1 | 71.4 | 100 | 76.5 | 57.1 |
| Hemicelluloses | 25.9 | 23.6 | 12.8 | 23.7 | 15.2 | 7.8 |
| Celluloses | 35.4 | 34.4 | 20.1 | 31.0 | 22.1 | 11.9 |
| Lignins | 13.0 | 12.1 | 11.8 | 10.2 | 10.1 | 9.1 |

It may be of interest to note first that the nitrogen content of the rye straw used in this experiment was 0.24% and of the corn stalks 0.66%. In the absence of additional inorganic fertilizer the rye straw underwent only very little decomposition, there being 7% reduction in bulk within four weeks at an optimum temperature and moisture. When inorganic nitrogen was added, there was a reduction of nearly one-third in the organic matter (28.6%). The hemicelluloses were reduced by 10.8% of the total dry organic matter and the celluloses by 14.3%, the reduction in the bulk of these two substances accounting for nearly 84% of the organic matter decomposed. This was accompanied by assimilation of about 30 mgm of nitrogen for every gram of organic matter that has disappeared in excess over the organic matter not receiving any additional nitrogen. The ratio between the nitrogen used up by the micro-organisms and the organic matter decomposed was about 1:33. In other words, for the complete decomposition of organic matter, if that were possible and desirable, one would have to supply 1 part of nitrogen in an inorganic form for every 33 parts of organic matter decomposed.

However, since only a certain part of the plant material undergoes rapid decomposition, a smaller amount of nitrogen will suffice for the preparation of composts on a practical scale. This will depend, of course, upon the nature and composition of the organic matter used in the preparation of the composts. Actually the use of about 1 part of nitrogen for every 140 parts of straw has been found to be economically advisable.

The corn stalks used in the previous experiment were less mature and contained a higher nitrogen content, as well as a larger amount of water-soluble substances, than the rye straw and, therefore, decomposed much more readily. Even without any additional inorganic fertilizer there was a disappearance of about one-quarter of the organic matter within a period of four weeks. But the addition of available inorganic nitrogen brought about a considerably greater degree of decomposition under these conditions, namely, 42.9% of the organic matter disappeared within this short period of time of which 15.9% was hemicellulose and 19.1% cellulose; here again over 81% of the organic matter decomposed was accounted for by these two groups of polysaccharides. There was as well a considerable transformation of the inorganic nitrogen into an organic form in a ratio very similar to the one found in the case of the rye straw.

These results bring out emphatically two distinct phenomena to be considered in the preparation of artificial composts, *viz.*, (a) since 80% or more of the constituents of the decomposed portion of the straw or other plant residues used in the preparation of the composts are made up of celluloses and hemicelluloses, the discussion may be limited to the decomposition of these two groups of polysaccharides to embrace the complete decomposition processes involved; and (b) since there is a definite relation between the celluloses decomposed and the inorganic nitrogen required by the organisms, a knowledge of the amount of nitrogen in the plant residues as well as some information concerning its cellulose and hemicellulose content, depending of course on the nature of the plant, will help in determining the amount of inorganic fertilizer which is to be added for the proper preparation of the composts.

To elucidate the problem further as well as to illustrate the preparation of composts in greater bulk, the results obtained in the following experiment will suffice.

Rye straw was used in this experiment and the effect of lime and of mineral fertilizers upon the nature and extent of the transformations taking place in the formation of artificial manure was determined.

Sufficient mature rye straw was placed in a series of large ash cans to give 18 pounds of dry material in each. Some of the cans received

200-gram quantities of $CaCO_3$; others received 200 grams of di-ammonium phosphate and 200 grams of KCl, another 200-gram quantity of the nitrogen salt being added four months later to those cans which received the first application of nutrients. Another series of cans received 200 grams of lime and nutrients. Sufficient water was added to make the moisture content of the composts 70%. The cans were kept in the greenhouse through the winter and the contents mixed at intervals of three to four weeks.

At the end of 290 days the composting mixtures receiving nothing but water were found (Tables 3 and 4) to have lost 25.8% of their initial dry weight; the composts receiving lime, 26.6%; the composts receiving inorganic nutrients, 43.5%; and the composts receiving lime and nutrients, 58.3%. In other words, while only one-quarter of the material was decomposed in the absence of additional nutrients, three-fifths of the dry matter disappeared in the presence of additional inorganic nutrients and lime. Lime had no effect upon the rapidity of decomposition when no inorganic salts were added, but it influenced decomposition markedly in the presence of additional inorganic fertilizer.

The differences become even more marked when one examines in detail the transformation of the various constituents of the rye straw in the process of decomposition. The fact that out of every 100 grams of straw to begin with there was left at the end of the period of composting only 41.7 grams does not mean at all that only 58.3% of the straw has been decomposed and that the remaining 41.7% consists of undecomposed material. Some of the constituents have decomposed very readily, as in the case of the celluloses, hemicelluloses, and ether-soluble substances, while others have decomposed very slowly, as in the case of the lignins, or have actually increased both in relative concentration and in the absolute amount, as in the case of the proteins.

Since the nitrogen part of the manure, next to the organic matter itself, is the most valuable constituent, it is worth while to consider what has taken place. The rye straw to start with had only 1.88% of water-insoluble protein or 0.30% of total nitrogen. The artificial manure, resulting from the composting of rye straw in the presence of additional water-soluble inorganic nitrogen salts, contained, at the end of 157 days, 14.94% water-insoluble proteins or 2.39% total nitrogen which was almost entirely in an organic form.

In other words, *the production of artificial manure from straw and other farm wastes consists in the decomposition by micro-organisms, largely fungi and bacteria, of most of the celluloses and hemicelluloses,*

TABLE 3.—*Influence of inorganic nutrients upon the nature and rapidity of decomposition of rye straw incubated for different periods.*

| Plant constituents | Original material | No additional nutrients | | $CaCO_3$ added | | | Mineral nutrients added | | | Mineral nutrients + $CaCO_3$ added | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 39 days | 290 days | 39 days | 96 days | 290 days | 39 days | 96 days | 290 days | 39 days | 96 days | 290 days |
| | % | % | % | % | % | % | % | % | % | % | % | % |
| Ether-soluble fraction | 1.68 | 0.82 | 0.43 | 1.07 | 1.22 | 0.51 | 1.50 | 0.97 | 0.55 | 1.38 | 1.01 | 0.41 |
| Water-soluble fraction | 5.75 | 7.58 | 4.16 | 5.94 | 3.12 | 2.76 | 4.08 | 5.29 | 6.69 | 6.13 | 6.43 | 8.73 |
| Alcohol-soluble fraction | — | — | 1.38 | — | — | 1.28 | — | — | 2.64 | — | — | 1.60 |
| Hemicelluloses | 26.41 | 27.00 | 20.94 | 26.75 | 25.49 | 23.45 | 26.14 | 22.28 | 16.08 | 24.44 | 21.60 | 14.77 |
| Celluloses | 36.13 | 36.43 | 35.48 | 33.12 | 30.30 | 31.01 | 33.41 | 25.70 | 17.41 | 32.00 | 23.18 | 13.75 |
| Lignins | 12.35 | 13.04 | 17.69 | 12.99 | 19.64 | 21.09 | 16.44 | 19.10 | 19.47 | 15.07 | 19.61 | 24.39 |
| Proteins | 1.88 | 2.06 | 3.43 | 3.12 | 2.81 | 3.38 | 3.69 | 6.81 | 14.50 | 3.94 | 8.06 | 14.56 |
| Ash | 3.72 | 4.00 | 5.84 | 6.39 | 10.00 | 10.04 | 9.26 | 11.04 | 19.32 | 9.56 | 11.13 | 19.44 |
| Total | 87.92 | 90.93 | 89.35 | 89.38 | 92.58 | 93.52 | 94.52 | 91.19 | 96.66 | 92.52 | 91.02 | 97.65 |

TABLE 4.—*Total plant constituents in the various composts as a result of decomposition for 290 days.*

| Plant constituents | At start | Grams of material: No additional nutrients | $CaCO_3$ added | Mineral nutrients added | Mineral nutrients + $CaCO_3$ added |
|---|---|---|---|---|---|
| Total | 8,100.0 | 6,012.0 | 6,111.0* | 4,550.0 | 3,884.0† |
| Ether-soluble fraction | 136.1 | 25.9 | 31.2 | 25.0 | 15.9 |
| Water-soluble fraction | 465.8 | 250.1 | 168.7 | 304.4 | 339.1 |
| Hemicelluloses | 2,139.2 | 1,260.9 | 1,433.0 | 731.6 | 573.7 |
| Celluloses | 2,926.5 | 2,133.1 | 1,895.0 | 792.2 | 534.2 |
| Lignins | 1,000.4 | 1,063.2 | 1,288.9 (?) | 885.9 | 947.3 |
| Proteins | 152.3 | 206.2 | 206.6 | 659.8 | 565.5 |

*If the higher ash content is accounted for, there will be somewhat more organic matter decomposed in the presence of $CaCO_3$ than in its absence.

†If the high ash content is accounted for, the amount decomposed in the presence of nutrients is even more marked.

*in an accumulation of lignins, and in a large total and proportionally greater percentage increase in the organic nitrogen compounds.*

To illustrate the similarity both in chemical composition and in the influence upon plant growth of the artificial manure with that of horse manure, composted under exactly the same conditions for the same period of time (290 days), the following results may be cited. These results were obtained in an experiment similar to the previous one, where freshly obtained horse manure was composted in cans parallel with the composts of artificial manure. The composition of the compost of horse manure is compared with the composition of the compost of artificial manure which consisted of straw receiving inorganic nitrogen salts, phosphates, and $CaCO_3$ (Table 5).

TABLE 5.—*Relative composition of artificial manure from straw and of horse manure composted under exactly the same conditions and for the same period of time.**

| Plant constituents | Artificial manure | Composted horse manure |
|---|---|---|
| | % | % |
| Ether-soluble | 0.41 | 0.95 |
| Soluble in cold and hot water | 8.73 | 5.71 |
| Hemicelluloses | 14.77 | 12.67 |
| Celluloses | 13.75 | 5.97 |
| Lignins | 24.39 | 28.43 |
| Protein | 14.56 | 16.38 |
| Ash | 19.44 | 19.32 |
| Total | 96.05 | 89.43 |

*On the basis of dry matter.

The results show that artificial manure properly prepared will be very similar in chemical composition and in the amount of organic nitrogenous compounds to composted horse manure.

To demonstrate the effect of these two manures upon plant growth, wheat and oats were grown in a series of pots containing definite quantities of Sassafrass soil.

The two composted manures were added at the rate of 5, 10, and 20 tons per acre. The crops were harvested, dried, weighed, and analyzed for nitrogen content. The crop yields from the artificial manure were in all cases as high and even higher than from the addition of the composted horse manure. The nitrogen content of the plants, which can serve as a measure of the nitrogen availability, was in all cases as high or higher than with the horse manure.

## DISCUSSION

The problems involved in the study of the principles underlying the decomposition of mature straw and other plant residues in composts leading to the formation of so-called artificial manure involve a knowledge of (a) the composition of the plant material, (b) mechanism of the decomposition processes which are brought about by the micro-organisms, and (c) a knowledge of the metabolism of these organisms.

Straw and other farm residues which are commonly used for the purpose of composting consist predominantly (60% or more) of celluloses and hemicelluloses which undergo rapid decomposition in the presence of sufficient nitrogen and other minerals, of lignins (15 to 20%) which are more resistant to decomposition and which gradually accumulate, of water-soluble substances (5 to 12%) which decompose very rapidly, of proteins which are usually present in very small amounts (1.2 to 3.0%) but which gradually increase in concentration with the advance of decomposition, and of the mineral portion or ash.

The processes of decomposition involved in the composting consist largely in the disappearance of the celluloses and hemicelluloses which make up more than 80% of the organic matter which is undergoing decomposition in the process of formation of artificial manures. These polysaccharides cannot be used as direct sources of energy by nitrogen-fixing bacteria and their decomposition depends entirely upon the action of various fungi and aerobic bacteria. In the process of decomposition of the celluloses and hemicelluloses, the microorganisms bring about the syntheses of microbial cell substance. This may be quite considerable, frequently equivalent to a fifth or

even more of the actual organic matter decomposed. To synthesize these large quantities of organic matter, the micro-organisms require large quantities of available nitrogen and phosphorus and a favorable reaction. The nitrogen and phosphorus are used for the building up of the proteins and nucleins in the microbial cells. Since there is a direct relation between the celluloses decomposed and the organic matter synthesized, it should be expected also that there would be a direct relation between the cellulose decomposed and the amount of nitrogen required. As a matter of fact, for every 40 or 50 parts of cellulose and hemicellulose decomposed 1 unit of available nitrogen has to be added to the compost.

As the plant residues used in the preparation of "artificial manure" are poor in nitrogen, available inorganic nitrogen must be introduced for the purpose of bringing about active decomposition. This explains the increase in the protein content of the compost accompanying the gradual decrease of the celluloses and hemicelluloses.

In general, artificial composts can be prepared from plant residues of any chemical composition so long as the nature of these residues and of the processes involved in their decomposition are known. By regulating the temperature and moisture content and by introducing the required amounts of nitrogen, phosphorus, potassium, and calcium carbonate, the speed of decomposition and the nature of the product formed can be controlled.

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# SOME EFFECTS OF MANGANESE SULFATE AND MANGANESE CHLORIDE ON NITRIFICATION[1]

D. H. NELSON[2]

## INTRODUCTION

The relationships of manganese compounds to plant growth have been studied quite extensively by several investigators during the last 35 years. While it has not been absolutely proved that manganese is an essential element, it is well established that when present in low concentrations it may exert a beneficial influence on some plants. It is not certain by any means that all plants require the same elements; and indeed it seems very probable that an element may be absolutely essential for one plant and quite unnecessary for another. While it has been shown that some plants are benefited by the presence of manganese, it is not known how it exerts its favorable action, although it is usually believed that it assists the oxidative processes in metabolism. Whether manganese acts as an oxidase or is a constituent of an organic oxidase, formed by the plant, is not entirely clear; but in either case the effects would be the same.

The question then arises, Do manganese compounds affect microorganisms in the same way that they effect the higher plants? Up to the present time there have been insufficient studies along this line to warrant a conclusion. However, since most bacteria seem to be closely related to higher plants, it is probable that the effects would be much the same.

One physiological group of soil organisms are able to obtain energy for life processes by oxidising ammonium compounds or nitrites. The process is spoken of as nitrification and the organisms are called nitrifiers. If it is true that manganese stimulates oxidative processes in higher plants, would it not be possible and even probable that it would stimulate the oxidative processes of these bacteria? It is with a hope of throwing more light on this subject that this work was planned.

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## REVIEW OF LITERATURE

Most of the work dealing with the effects of manganese on living organisms has been carried out with higher plants. Numerous pot and field tests have been made using varying amounts of different manganese compounds mixed with the soil and growing plants of various kinds. The dry weight of the crop or the weight of grain, or both, have been taken as a measure of the effectiveness of the treatments. This work has been well reviewed by Olrau (9)[3] and Brenchley (1) and extensive bibliographies given.

Skinner and Sullivan (13) found that manganese salts increased the oxidizing power of plant roots in poor soils, and stimulated growth. In rich soils oxidation was increased but plant growth was retarded, the plants showing indications of excessive oxidation. When 50 pounds per acre were added the oxidizing power of the soil was decreased and the crop yield lowered. The latter result they suggest was probably due to the fact that the soils were acid in character.

Skinner and Reid (12) studied the effects of manganese sulfate on an acid soil using 50 pounds of the salt per acre. They found that the oxidative power of the soil was increased only when the soil was neutralized with calcium carbonate before the manganese was added. The yields of wheat, rye, corn, and cowpeas were increased, but there was no effect on potatoes. When manganese was added to the soil without neutralizing the acidity, the oxidative power was decreased as well as the yields.

Schreiner and Sullivan (11) found that oxidation in soils is increased by salts of manganese, iron, aluminum, calcium, and magnesium, especially in the presence of hydroxy acids, such as citric, tartaric, malic, glycolic, and their salts. The best oxidation was obtained by the addition of manganese. The authors believe this property of manganese salts is sufficient to account for the stimulating effects it often shows on crop growth.

Kelley (5), in a study of Hawaiian soils, found that the various species of bacteria vary considerably in their behavior toward manganese just as is the case with different higher plants. Nitrification took place more rapidly in manganiferous soils than in normal soils, while ammonification was about the same in both. He believes that the aeration was quite largely responsible for this as the normal soil used was more compact and hence not so well aerated. Later experiments (6) confirmed these results.

Brown and Minges (2) studied the effects of manganese sulfate, manganese chloride, manganese nitrate, and manganese oxide on

[3]Reference by number is to "Literature Cited," p. 560.

ammonification and nitrification in Carrington loam. Manganese chloride in amounts of 100 pounds to 200 pounds per acre increased nitrification, while greater amounts depressed it. Manganese sulfate in amounts up to 100 pounds per acre stimulated nitrification, but larger applications up to 200 pounds per acre had no influence. Manganese nitrate in all amounts used depressed nitrification as did also manganese oxide.

Montanari (8), using 50-gram portions of soil treated with varying amounts of manganese oxide, manganese sulfate, or manganese carbonate, found that nitrification was stimulated by all concentrations used. The samples were incubated in petri dishes and 0.5 gram of manganese per 50 grams of soil was the highest concentration used.

Leoncini (7) conducted experiments with lime soils, clay soils, and humus soils to determine the effects of manganese dioxide and natural manganese hydrate on the nitrification of ammonium sulfate. In amounts up to 0.184% these compounds stimulated nitrification but in larger amounts nitrification was retarded or inhibited.

Greaves, Carter, and Goldthorpe (4) tested the effects of several salts of manganese on nitrification in a calcareous loam. Every salt tested showed stimulation in one or more of the concentrations used and all became toxic at the higher concentrations.

Deatrick (3) found that 10 to 20 p.p.m. of manganese sulfate did not affect the nitrifying power of the soil. Larger amounts of manganese checked nitrification.

Pietruszczynski (10) studied the influence of manganese salts on nitrification. All were found to increase nitrification when they were used in low concentrations. Of the salts tested, manganese sulfate had the greatest stimulating effect followed in order by manganese chloride and manganese carbonate. Soil and liquid cultures showed about the same results.

It is clear from the above brief review that manganese compounds influence oxidative processes in the soil and that the nitrifying bacteria may be stimulated by certain concentrations of manganese compounds.

## PROCEDURE

It is clear from an examination of the papers dealing with the influence of manganese salts on nitrification that the negative ion has not often been adequately considered. The salt or salts have in most cases been added to the soil or solution and the amount of oxidized nitrogen determined after the incubation period. It is not clear from such data whether the effects noted were due to the

manganese, the negative ion, or to both; and the amount of the effect due to each is entirely unknown. Of course, it is impossible to add manganese to a soil, except as the metal, without adding at the same time some other constituent. The fault is not so much with the method as with the interpretation of the results.

Greaves (4) studied several salts in series having common anions all used in molar equivalents. Comparisons were then made of all chlorides, all nitrates, etc., as a measure of the effects produced by the various positive ions. This is perhaps the most satisfactory method for a study of this kind so far employed, but it required an enormous amount of work. The author wished to get some idea of the effects due to the negative ions, but could not do the extensive work necessary by this method owing to a lack of time. It was thought advisable to supply an equivalent concentration of the negative ions by using a mixture of salts. In this way each positive ion would be present in small concentration, the amount diminishing with the number of salts used in the mixture Then by using positive ions common in the soil the effects of the small amounts of each positive ion added would be relatively slight, while the negative ion concentration would be equal to that of the soil treated with the manganese salt.

With this purpose in mind, sulfate and chloride solutions were prepared which were equivalent in sulfate and chloride content per cc to the manganese sulfate and manganese chloride solutions used. The sulfate solution was made up in such a way that an equal proportion of the sulfate ion was supplied by each of the following salts: $MgSO_4$, $K_2SO_4$, $NaSO_4$, and $Fe_2(SO_4)_3$. This solution will be called the sulfate solution in the tables. A similar chloride solution was prepared whose concentration of chloride ions per cc was equal to that of the manganese chloride solution used. The following salts were used, each supplying an equal proportion of the chloride ions: KCl, NaCl, $MgCl_2$, $CaCl_2$, and $FeCl_3$. This solution will be called the chloride solution in the tables.

By using these solutions soils could be treated with concentrations of $SO_4$ ions and Cl ions equal to those added with the manganese treatments. The positive ions would each be increased very slightly, and since common soil ions were used, it was believed that their effects would be at a minimum. However, it should be emphasized that a comparison is being made between manganese and a number of positive ions together since these are the only conditions not kept as nearly alike as possible. If manganese does not stimulate nitrification compared in this way, it will at least be safe to conclude that

its use for stimulating purposes would be undesirable, for the salts compared are cheaper and more easily available than manganese salts.

This work was done in the summer and fall of 1927. The soils used were Carrington loam and Webster loam taken from the Agronomy Farm of the Iowa Agricultural Experiment Station. The soils were air dried, sieved, and stored in earthenware jars.

The tumbler method was used to study nitrification, 100 grams of soil being used for each sample. Dried blood containing 108.5 mgm nitrogen per gram was added at the rate of 1% and ammonium sulfate sufficient to supply 30 mgm of nitrogen per 100 grams of soil was used. The samples were all incubated at room temperature in the dark in duplicate. The moisture content of the soils was made up to the optimum at the beginning of the experiment and once each week during incubation by weighing the samples and making up the loss in weight with distilled water.

The phenoldisulfonic acid method was employed for all nitrate determinations, the chlorides being removed with silver sulfate in the chloride series.

TABLE 1.—*Constituents per 100 grams of dry soil.*

| Soil type | pH | Moisture in grams | Total N in mgm | Nitrate N in mgm | Ammonia N in mgm | Nitrite N in mgm | Manganese in mgm |
|---|---|---|---|---|---|---|---|
| Webster loam... | 8.1 | 5.20 | 364.0 | 0.81 | 1.71 | trace | 1.12 |
| Carrington loam | 6.5 | 3.02 | 252.0 | 0.15 | 1.54 | trace | 1.00 |

Table 1 shows the amount of various constituents in the soils used. These data show the condition of the soils from the standpoint of those factors most essential in this study. It should be noted that the Webster soil is much higher in total nitrogen, is basic in reaction, and contains slightly more nitrate nitrogen and total manganese. The Carrington soil, on the other hand, is comparatively low in total nitrogen and shows an acid reaction. It was decided to test this soil in its natural condition as well as with the acidity neutralized with $CaCO_3$.

## RESULTS

### TESTS WITH MANGANESE SULFATE

The results of the nitrification tests are shown in Tables 2 to 11, inclusive.

In these tables the first column gives the various treatments of manganese as mgms of manganese supplied as manganese sulfate

or manganese chloride. The other columns show milligrams of nitrate nitrogen per 100 grams of soil at the end of the incubation period and the pH values of the respective soils at the time of analysis. When the sulfate solution was used the soils received varying amounts of the solution sufficient to make the sulfate ions equal to those in the soils treated with manganese sulfate. In Table 2, for example, the soil receiving 0.01 mgm of manganese as manganese sulfate contained 125.7 mgm nitrate nitrogen, while that receiving a similar $SO_4$ concentration as a sulfate mixture contained 137.8 mgm nitrate nitrogen. This arrangement was chosen to facilitate the examination of corresponding treatments in parallel columns.

TABLE 2.—*Effects of manganese sulfate and various other sulfates on nitrification in Webster loam.*

| Mgm of Mn as $MnSO_4$ | With $MnSO_4$ Mgm of nitrate N | pH | With sulfate solutions* Mgm of nitrate N | pH | With $MnSO_4$ Mgm of nitrate N | pH | With sulfate solutions* Mgm of nitrate N | pH |
|---|---|---|---|---|---|---|---|---|
| | With Dried Blood | | | | With Ammonium Sulfate | | | |
| Check | 126.8 | 7.4 | 126.8 | 7.4 | 27.3 | 7.7 | 27.3 | 7.7 |
| 0.01 | 125.7 | 7.4 | 137.8 | 7.4 | 29.2 | 7.8 | 30.7 | 7.7 |
| 0.10 | 106.1 | 7.5 | 135.2 | 7.4 | 30.8 | 7.7 | 31.7 | 7.7 |
| 1.00 | 137.8 | 7.5 | 138.4 | 7.4 | 29.8 | 7.7 | 30.7 | 7.8 |
| 5.00 | 129.3 | 7.4 | 134.8 | 7.5 | 31.1 | 7.8 | 28.0 | 7.7 |
| 10.00 | 117.0 | 7.6 | 138.9 | 7.4 | 30.4 | 7.9 | 24.8 | 7.7 |
| 25.00 | 119.5 | 7.6 | 126.8 | 7.5 | 28.7 | 8.0 | 28.7 | 7.8 |

*This solution was made up of $MgSO_4$, $K_2SO_4$, $Na_2SO_4$, and $Fe_2(SO_4)_3$ so that an equal amount of $SO_4$ ion was supplied by each salt. The solution has the same $SO_4$ concentration per cc as the manganese solution used.

An examination of Table 2 shows that in the case of the dried blood all the added nitrogen was nitrified and hence a comparison of rates of nitrification would be of little value. There is a lower nitrification of the nitrogen in the presence of manganese sulfate than in the presence of an equivalent amount of sulfates from the sulfate solution. In only two cases is more nitrogen oxidized in the presence of manganese than in similar untreated soil, while with the sulfate solution there was a higher oxidation in all but one case and then it was equal to that in the untreated soil.

In every case more ammonium sulfate was nitrified in the presence of manganese sulfate than in untreated soil, but the same was true in the presence of the sulfate solution in all but two cases. With 5 mgm and 10 mgm of manganese, respectively, there was a decided stimulation of nitrification by the manganese sulfate, but in lower concentrations the sulfate solution brought about a higher oxidation.

TABLE 3.—*Effects of manganese sulfate and various other sulfates on nitrification in Carrington loam.*

| Mgm of Mn as $MnSO_4$ | With $MnSO_4$ Mgm of nitrate N | pH | With sulfate solutions* Mgm of nitrate N | pH | With $MnSO_4$ Mgm of nitrate N | pH | With sulfate solutions* Mgm of nitrate N | pH |
|---|---|---|---|---|---|---|---|---|
| | With Dried Blood | | | | With Ammoniun Sulfate | | | |
| Check | 69.6 | 5.2 | 69.6 | 5.2 | 5.75 | 5.3 | 5.7 | 5.3 |
| 0.01 | 57.4 | 5.5 | 59.0 | 5.4 | 7.42 | 5.3 | 15.3 | 5.2 |
| 0.10 | 74.2 | 5.5 | 57.2 | 5.3 | 7.42 | 5.3 | 19.5 | 5.3 |
| 1.00 | 61.9 | 5.5 | 60.2 | 5.3 | 8.96 | 5.3 | 22.8 | 5.1 |
| 5.00 | 65.1 | 5.6 | 53.4 | 5.4 | 6.82 | 5.5 | 18.8 | 5.1 |
| 10.00 | 49.8 | 5.6 | 43.0 | 5.1 | 5.97 | 5.6 | 25.1 | 5.1 |
| 25.00 | 35.4 | 6.2 | 37.8 | 5.3 | 5.09 | 5.5 | 13.6 | 5.2 |

*This solution was made up of $MgSO_4$, $K_2SO_4$, $Na_2SO_4$, and $Fe_2(SO_4)_3$ so that an equal amount of $SO_4$ ion was supplied by each salt. The solution had the same $SO_4$ concentration per cc as the manganese solution used.

TABLE 4.—*Effects of various amounts of manganese sulfate and other sulfates on nitrification in Carrington loam neutralized with $CaCO_3$.*

| Mgm of Mn as $MnSO_4$ | With $MnSO_4$ Mgm of nitrate N | pH | With sulfate solutions* Mgm of nitrate N | pH | With $MnSO_4$ Mgm of nitrate N | pH | With sulfate solutions* Mgm of nitrate N | pH |
|---|---|---|---|---|---|---|---|---|
| | With Dried Blood | | | | With Ammonium Sulfate | | | |
| Check | 123.9 | 6.7 | 123.9 | 6.7 | 31.7 | 7.1 | 31.7 | 7.1 |
| 0.01 | 65.9 | 6.5 | 100.1 | 6.5 | 19.7 | 7.2 | 24.5 | 7.3 |
| 0.10 | 64.3 | 6.6 | 86.0 | 6.8 | 19.3 | 7.1 | 26.0 | 7.4 |
| 1.00 | 127.9 | 6.4 | 105.0 | 6.4 | 30.1 | 7.2 | 25.8 | 7.2 |
| 5.00 | 94.4 | 6.4 | 84.2 | 7.0 | 27.2 | 7.2 | 24.5 | 7.2 |
| 10.00 | 98.1 | 6.9 | 82.7 | 6.3 | 25.7 | 7.3 | 25.7 | 7.1 |
| 25.00 | 89.3 | 7.0 | 88.0 | 6.2 | 30.7 | 7.1 | 23.8 | 7.2 |

*This solution was made up of $MgSO_4$, $K_2SO_4$, $Na_2SO_4$, and $Fe_2(SO_4)_3$ so that an equal amount of $SO_4$ ion was supplied by each salt. The solution had the same $SO_4$ concentration per cc as the manganese solution used.

Tables 3 and 4 show the effects of reaction on nitrification. Only 69.6 mgm of nitrogen were nitrified in the natural soil, while in the soil treated with 0.5 gram of $CaCO_3$ all of the added nitrogen was nitrified and 15.4 mgm of the soil's own nitrogen besides. There was a slight stimulation of nitrification of dried blood where 0.1 mgm of manganese was added to the unlimed soil; otherwise, all manganese and sulfate solution treatments resulted in depressions. In the case of ammonium sulfate up to 10 mgm of manganese stimulated the oxidation in the acid soil, but the sulfate solution gave a much greater corresponding stimulation in every case. For the limed soil 1.0 mgm of manganese stimulated nitrification of the dried blood, while all other treatments had no effect or depressed oxidation.

There is no regularity in these results owing perhaps to the long incubation period chosen. Two of the sets were repeated using a 14-day incubation period. The results are given in Tables 5 and 6.

TABLE 5.—*Effects of manganese sulfate and various other sulfates on nitrification in Webster loam.*

| Mgm of Mn as $MnSO_4$ | With $MnSO_4$ Mgm of nitrate N | pH | With sulfate solutions* Mgm of nitrate N | pH | With $MnSO_4$ Mgm of nitrate N | pH | With sulfate solutions* Mgm of nitrate N | pH |
|---|---|---|---|---|---|---|---|---|
| | With Dried Blood | | | | With Ammonium Sulfate | | | |
| Check | 32.3 | 6.8 | 32.3 | 7.0 | 20.3 | 7.0 | 20.3 | 7.0 |
| 0.01 | 29.8 | 6.8 | 40.6 | 6.9 | 21.5 | 6.9 | 20.5 | 7.0 |
| 0.10 | 32.1 | 6.9 | 38.4 | 7.0 | 18.2 | 6.9 | 19.2 | 7.0 |
| 1.00 | 32.3 | 6.9 | 41.6 | 7.0 | 20.3 | 7.0 | 20.8 | 7.0 |
| 5.00 | 29.2 | 7.1 | 39.1 | 7.0 | 20.8 | 7.0 | 18.7 | 6.9 |
| 10.00 | 29.4 | 7.5 | 34.3 | 7.2 | 19.5 | 7.1 | 21.8 | 6.9 |
| 25.00 | 30.4 | 7.2 | 33.2 | 7.1 | 20.1 | 7.2 | 23.2 | 7.1 |
| 50.00 | 21.8 | 7.3 | 35.0 | 7.1 | 16.1 | 7.4 | 15.6 | 7.0 |

*This solution was made up of $MgSO_4$, $K_2SO_4$, $NaSO_4$, and $Fe_2(SO_4)_3$ so that an equal amount of $SO_4$ ion was supplied by each salt. The solution had the same $SO_4$ concentration per cc as the manganese solution used.

Table 5 shows that there was no stimulation in the nitrification of dried blood and but very slight stimulation in the nitrification of ammonium sulfate by the various manganese treatments on the Webster loam. It should be noted, too, that even 50 mgm of manganese as manganese sulfate did not stop nitrification. The sulfate solution was more stimulating than manganese sulfate in every case when dried blood was used and in all but three cases where ammonium sulfate was employed. In these exceptional cases the differences were very small.

TABLE 6.—*Effects of manganese sulfate and various other sulfates on nitrification in Carrington loam neutralized with $CaCO_3$.*

| Mgm of Mn as $MnSO_4$ | With $MnSO_4$ Mgm of nitrate N | pH | With sulfate solutions* Mgm of nitrate N | pH | With $MnSO_4$ Mgm of nitrate N | pH | With sulfate solutious* Mgm of nitrate N | pH |
|---|---|---|---|---|---|---|---|---|
| | With Dried Blood | | | | With Ammonium Sulfate | | | |
| Check | 36.7 | 6.7 | 36.7 | 6.9 | 17.0 | 7.0 | 17.0 | 7.4 |
| 0.01 | 33.5 | 6.8 | 25.0 | 7.0 | 17.8 | 7.1 | 15.8 | 7.4 |
| 0.10 | 39.2 | 6.8 | 37.9 | 6.8 | 17.4 | 7.4 | 18.3 | 7.3 |
| 1.00 | 39.4 | 6.8 | 27.1 | 6.9 | 18.3 | 7.4 | 17.6 | 7.3 |
| 5.00 | 44.5 | 6.9 | 30.0 | 6.9 | 16.1 | 7.5 | 19.8 | 7.3 |
| 10.00 | 30.9 | 7.1 | 30.3 | 6.9 | 14.5 | 7.6 | 19.2 | 7.3 |
| 25.00 | 29.1 | 7.1 | 17.9 | 7.1 | 15.4 | 7.6 | 19.6 | 7.2 |
| 50.00 | 19.7 | 7.3 | 19.6 | 7.1 | 15.7 | 7.7 | 18.4 | 7.2 |

*This solution was made up of $MgSO_4$, $K_2SO_4$, $Na_2SO_4$, and $Fe_2(SO_4)_3$ so that an equal amount of $SO_4$ ion was supplied by each salt. The solution had the same $SO_4$ concentration per cc as the manganese solution used.

In the Carrington loam (Table 6) where $CaCO_3$ had been added, 0.10, 1.0, and 5.0 mgm of manganese as manganese sulfate stimulated the nitrification of dried blood, and in every case more nitrogen was oxidized than in the soils treated with an equivalent of the sulfate solution. With ammonium sulfate the case was different. Here there was a slight stimulation in nitrification where 0.01 mgm or 1.0 mgm of manganese was added, but the sulfate solution showed a stimulation in all but one case. The higher concentrations of manganese did not reduce nitrification more than 50% in the case of dried blood and only about 4% with ammonium sulfate. This is quite remarkable considering that the application was equivalent to about 2.5 tons of manganese sulfate per acre, or an amount sufficient to give the soil a content of 0.05% manganese.

## SAND AND SOLUTION TESTS

*With sand.*—Fifty-gram portions of well-washed sand were weighed into tumblers and treated with a nutrient solution containing per liter $K_2HPO_4$, 1 gram; NaCl, 2 grams; $MgSO_4$, 0.5 gram; $Fe_2SO_4$, trace; and sufficient ammonium sulfate to supply 17.2 mgm nitrogen per sample. The tumblers were incubated for 28 days at room temperature after receiving 5 cc of a soil suspension each. The nitrates were determined in the usual way and the results are given in Table 7.

TABLE 7.—*Influence of $MnSO_4$ on nitrification of ammonium sulfate in sand.*

| | | Mgm manganese as $MnSO_4$ | | | | | |
|---|---|---|---|---|---|---|---|
| | Check | 0.005 | 0.05 | 0.50 | 2.50 | 5.00 | 12.50 |
| Nitrate N in mgm | 5.92 | 3.40 | 3.05 | 3.25 | 5.64 | 3.66 | 2.14 |

A glance at this table shows that manganese sulfate had a depressing effect, but this was not regular in nature nor in proportion to the concentration of manganese ions present. Unfortunately, the series treated with the sulfate solution was lost and not repeated for lack of time. However, there was so much sulfate in the solution that a small addition would probably not have increased the nitrification.

*With solution.*—A solution was prepared having the same constituents as those used with sand, but with only 15.0 mgm of nitrogen as ammonium sulfate per 100 cc of solution. One hundred-cc portions were placed in flasks and sterilized. An excess of $CaCO_3$ was then added and 5 cc of a soil suspension introduced into each flask. Manganese sulfate was added to one series in varying amounts and the sulfate solution to another. After 28 days the cultures were analysed for nitrates. The results are given in Table 8.

TABLE 8.—*Effects of manganese sulfate on nitrification in solution with ammonium sulfate.*

| Mgm of Mn as $MnSO_4$ | Mgm of nitrate N | |
|---|---|---|
| | With $MnSO_4$ | With sulfate solution* |
| Check | 11.57 | 11.57 |
| 0.01 | 11.78 | 12.76 |
| 0.10 | 11.92 | 11.08 |
| 1.00 | 11.85 | 12.90 |
| 5.00 | 11.99 | 12.90 |
| 10.00 | 11.54 | 13.04 |

*This solution was made up of $MgSO_4$, $K_2SO_4$, $Na_2SO_4$, and $Fe_2(SO_4)_3$ so that an equal amount of $SO_4$ ion was supplied by each salt. The solution had the same $SO_4$ concentration per cc as the manganese solution used.

From this table it is clear that a slight stimulation occurred with all but the highest amounts of manganese sulfate and that even here there was no depression. However, only in the case of 0.1 mgm of manganese did the manganese treatments give a higher result than the corresponding sulfate solution treatment. In all other cases the sulfate solution was more stimulating. With the solution tests the manganese of the soil is practically eliminated as a factor, but the results are similar to those obtained with the soil cultures.

## TESTS WITH MANGANESE CHLORIDE

These tests were similar to those carried out with the sulfate. Table 9 shows the effects of manganese chloride and various other chlorides on the nitrification of dried blood and ammonium sulfate in the Webster loam.

TABLE 9.—*Effects of manganese chloride and other chlorides on nitrification in Webster loam.*

| Mgm of Mn as $MnCl_2$ | With $MnCl_2$ | | With chloride solution* | | With $MnCl_2$ | | With chloride solution* | |
|---|---|---|---|---|---|---|---|---|
| | Mgm of nitrate N | pH | Mgm of nitrate N | pH | Mgm of nitrate N | pH | Mgm of nitrate N | pH |
| | With Dried Blood | | | | With Ammonium Sulfate | | | |
| Check | 13.4 | 7.9 | 13.4 | 7.9 | 9.5 | No pH | 9.5 | No pH |
| 0.01 | 11.5 | 8.0 | 18.3 | 7.9 | 8.5 | values | 7.1 | values |
| 0.10 | 19.1 | 7.9 | 16.6 | 8.0 | 11.1 | deter- | 9.8 | deter- |
| 1.00 | 15.4 | 7.9 | 17.4 | 7.8 | 7.7 | mined | 8.5 | mined |
| 5.00 | 16.6 | 8.0 | 10.7 | 7.9 | 8.4 | | 9.3 | |
| 10.00 | 11.5 | 8.1 | 13.4 | 7.8 | 6.2 | | 8.9 | |
| 25.00 | 7.1 | 8.1 | 10.0 | 8.0 | 5.0 | | 8.8 | |
| 50.00 | 4.6 | 7.8 | 5.4 | 8.0 | 2.6 | | 6.1 | |

*This solution was made up of $MnCl_2$, $KCl$, $NaCl$, $CaCl_2$, and $FeCl_3$ so that an equal amount of Cl ion was supplied by each salt. The solution had the same Cl concentration per cc as the manganese solution used.

Comparing these results with those reported in Table 2, it is quite noticeable that the total amounts of nitrogen nitrified were much smaller with the chlorides than with the sulfates. This cannot be due to the chlorides, however, for the nitrate nitrogen accumulation in the untreated soil was correspondingly low. The only factor which can be suggested to account for this is temperature. This work was done in December, while the previous work was done in September. Room temperature was used in both cases and there was probably a difference of 3 to 5 degrees F.

In three cases where dried blood was used the chloride solution showed a greater stimulation than the manganese chloride. Where 0.10 mgm of manganese as the chloride was added the nitrification was at its highest. There was no regularity in the stimulation, however, and no given concentration was superior in all cases.

The results with ammonium sulfate were more nearly uniform for both the manganese chloride and the chloride solution. There was a slight stimulation with 0.01 mgm of manganese. The chloride solution showed the greatest stimulation with an amount equivalent to 25 mgm of manganese. It is noticeable that even the highest applications did not reduce the nitrifying power more than 10 to 15%.

With the Carrington loam, the unlimed soil was incubated 28 days. The results are shown in Table 10.

TABLE 10.—*Effects of manganese chloride and various other chlorides on nitrification in Carrington loam.*

| Mgm of Mn as $MnCl_2$ | With Dried Blood: With $MnCl_2$ Mgm of nitrate N | pH | With Dried Blood: With chloride solution* Mgm of nitrate N | pH | With Ammonium Sulfate: With $MnCl_2$ Mgm of nitrate N | pH | With Ammonium Sulfate: With chloride solution* Mgm of nitrate N | pH |
|---|---|---|---|---|---|---|---|---|
| Check | 49.1 | 5.1 | 49.1 | 5.2 | 11.8 | 5.4 | 11.8 | 5.4 |
| 0.01 | 49.4 | 5.1 | 45.5 | 5.3 | 12.3 | 5.3 | 12.5 | 5.4 |
| 0.10 | 47.8 | 5.2 | 47.1 | 5.1 | 12.1 | 5.3 | 12.9 | 5.3 |
| 1.00 | 45.5 | 5.1 | 47.7 | 5.2 | 10.9 | 5.4 | 12.1 | 5.4 |
| 5.00 | 42.7 | 5.3 | 46.6 | 5.2 | 10.1 | 5.4 | 11.9 | 5.3 |
| 10.00 | 33.4 | 5.7 | 40.0 | 5.2 | 7.8 | 5.6 | 11.8 | 5.4 |
| 25.00 | 23.3 | 6.1 | 38.5 | 5.4 | 3.9 | 5.8 | 10.0 | 5.4 |
| 50.00 | 16.0 | 6.4 | 23.2 | 5.9 | 0.9 | 6.0 | 5.2 | 5.7 |

*This solution was made up of $MnCl_2$, KCl, NaCl, $CaCl_2$, and $FeCl_3$ so that an equal amount of Cl ion was supplied by each salt. The solution had the same Cl concentration per cc as the manganese solution used.

This table shows that there was no stimulation in any case where dried blood was used, either with the manganese chloride or the chloride solution. At the higher concentrations the manganese was more toxic than the corresponding concentrations of chloride solution.

With ammonium sulfate there was a slight stimulation with 0.01 and 0.1 mgm of manganese chloride, but with higher concentrations the toxicity is very marked practically stopping nitrification at 50 mgm of manganese. With the chloride solution the stimulation with the lower concentrations was more marked than with the manganese chloride; and with the higher concentrations, less toxic.

TABLE 11.—*Effects of manganese chloride and various other chlorides on nitrification in Carrington loam neutralized with $CaCO_3$.*

| Mgm of Mn as $MnCl_2$ | With $MnCl_2$ | | With chloride solution* | | With $MnCl_2$ | | With chloride solution* | |
|---|---|---|---|---|---|---|---|---|
| | Mgm of nitrate N | pH | Mgm of nitrate N | pH | Mgm of nitrate N | pH | Mgm of nitrate N | pH |
| | With Dried Blood | | | | With Ammonium Sulfate | | | |
| Check | 32.4 | 7.2 | 32.4 | 7.1 | 10.4 | 7.4 | 10.4 | 7.6 |
| 0.01 | 32.8 | 7.1 | 38.7 | 7.1 | 13.8 | 7.5 | 13.4 | 7.5 |
| 0.10 | 31.8 | 7.1 | 31.2 | 7.2 | 14.3 | 7.4 | 13.8 | 7.5 |
| 1.00 | 32.8 | 7.1 | 31.9 | 7.2 | 14.3 | 7.6 | 13.4 | 7.5 |
| 5.00 | 29.8 | 7.0 | 32.2 | 7.3 | 10.5 | 7.7 | 12.5 | 7.6 |
| 10.00 | 24.4 | 7.3 | 30.5 | 7.3 | 11.8 | 7.8 | 12.9 | 7.5 |
| 25.00 | 16.6 | 7.4 | 25.0 | 7.3 | 8.3 | 7.7 | 9.8 | 7.6 |
| 50.00 | 6.0 | 7.4 | 12.6 | 7.5 | 2.5 | 7.6 | 7.2 | 7.6 |

*This solution was made up of $MnCl_2$, KCl, NaCl, $CaCl_2$, and $FeCl_3$ so that an equal amount of Cl ion was supplied by each salt. The solution had the same Cl concentration per cc as the manganese solution used.

Table 11 shows the effects of lime. While there was no stimulation in the nitrification of the dried blood with the manganese chloride, the toxic effects of the higher concentrations were markedly reduced. The chloride solution showed a slight stimulation at low concentrations (0.01 mgm) and was less toxic at the higher concentrations.

With ammonium sulfate there was a marked stimulation with low concentrations of manganese chloride and the $CaCO_3$ markedly reduced the toxicity of the manganese at the higher concentrations. The chloride solution showed less stimulation at lower concentrations, but was much less toxic at higher concentrations.

## DISCUSSION AND SUMMARY

Studies on some effects of $MnSO_4$ and $MnCl_2$ and of other sulfates and chlorides on the nitrification of dried blood and ammonium sulfate in Carrington loam and Webster loam are reported. Comparisons are made between the soils treated with the manganese salts and the same soils treated with sulfates or chlorides in amounts sufficient to give these soils the same negative ion concentration as the soils treated with manganese. The sulfate solution was prepared by using $MgSO_4$, $K_2SO_4$, $Na_2SO_4$, and $Fe_2(SO_4)_3$ in such amounts

that each salt supplied an equal proportion of the sulfate ion per cc. The chloride solution was prepared by using $FeCl_3$, KCl, NaCl, $MgCl_2$, and $CaCl_2$ in such amounts that each salt supplied an equal proportion of the chloride ion per cc.

The results reported show that manganese salts may stimulate or depress nitrification, but the degree of stimulation or depression does not follow regularly with the increase in amount of manganese salts applied. There was no particular concentration of manganese which proved stimulating in all cases, nor were the largest amounts applied always the most toxic. However, the toxic effects were more regular than the stimulating effects, usually increasing with the larger applications.

The effects of the sulfate and chloride solutions were similar to those brought about by the manganese sulfate and chloride, differing chiefly in degree. The solutions were in all cases less toxic in the large applications than were the manganese salts in the same concentrations. However, there was no regular stimulation nor toxic effect with the small applications.

Lime has a definite influence in reducing the toxic effect of manganese on nitrification. This is undoubtedly due to the change in reaction for it is generally true that a basic soil has a higher nitrifying power than a similar acid soil. The sand and solution tests were not extensive enough to warrant general conclusions; however, it is clear that manganese treatments bring about little or no stimulation in nitrification, at least as far as tested in these experiments.

## CONCLUSIONS

1. Manganese compounds in small concentrations may stimulate the nitrification of dried blood or ammonium sulfate in soil.

2. There is no regularity of relationship between the concentration of manganese and the stimulation in nitrification.

3. The stimulation in nitrification noted in the presence of manganese salts may be due to the negative ion and not to the manganese.

4. High concentrations of manganese salts retard nitrification but do not stop the process.

5. Lime is very effective in reducing the toxic effects of manganese on nitrification in soil.

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# THE CHEMICAL COMPOSITION OF *ANDROPOGON VIRGINICUS* AND *DANTHONIA SPICATA* AT SUCCESSIVE GROWTH STAGES[1]

R. B. DUSTMAN and L. C. SHRIVER[2]

Large areas of the less fertile meadow and grazing lands of the eastern United States are more or less liberally sprinkled, dotted, or covered with two species of wild pasture grasses, *viz.*, *Andropogon virginicus*, commonly called broomsedge, and *Danthonia spicata*, locally known as "poverty grass" or "moonshine grass." Both grasses are generally despised by farmers and stockmen as indicative of poor soil and low grazing capacity. Without doubt, they merit, at least in part, the low esteem in which they are held. Yet they frequently maintain an existence and even flourish where more highly prized species would fail. Observations indicate that under certain conditions at present not well understood, Kentucky bluegrass and white clover follow in ecological succession, crowding out the less desirable broomsedge and poverty grass after the latter have run their course over a period of years. But irrespective of our regard or lack of regard for them, their presence over such widespread areas demands consideration and raises the question of how best to utilize, if utilization is indeed possible, the plants already established.

## PREVIOUS INVESTIGATIONS

A brief survey of the literature discloses that but few chemical investigations have been made on these species. They were mentioned occasionally in the literature of a quarter century or more ago but in recent years have apparently been passed by for material of greater promise. Jordan (2),[3] in 1888, reported a single analysis of *D. spicata* at the time of full bloom. Using the plants harvested at this stage, he gives also the results of some digestion trials with sheep.

Tracy (4), in 1895, gives a similar analysis for *A. virginicus* collected in September. In 1893, Patterson (3) at the Maryland Station tried ensiling mature broomsedge in alternate layers with corn silage. He reported that in the winter this broomsedge silage came out in soft condition and was eaten with a relish by the stock, none being

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[3]Reference by number is to "Literature Cited," p. 567.

TABLE 1.—*Time and stage of collecting samples.*

| Date collected | | Description |
|---|---|---|
| | | *Andropogon virginicus* from Open Hillside Pasture, 1927 |
| May 5 | | Old growth from previous season (1926). Culms and leaves dead and brown but not decayed. |
| May 5 | | First growth 2 to 4 inches long. Tips frosted. Blades separated from old sheaths of previous season's growth. |
| June 6 | | Blades 4 to 10 inches long. Still well protected by old growth. |
| July 6 | | Growth 6 to 18 inches. Beginning to branch out from old leaves and stems. |
| Aug. 15 | | Growth 15 to 24 inches. No culms showing. |
| Sept. 15 | | Growth 15 to 30 inches. Culms formed but still green. Feather-like tuftings beginning to appear. |
| Oct. 17 | | Growth 15 to 30 inches. Still partly green and interspersed with dead brown stalks of previous season's growth. Seeds ripened. |
| | | *Andropogon virginicus* from Open Hillside, Uncut Meadow, 1928 |
| May 7 | | Old growth from previous season (1927). Culms and leaves dead and brown but not decayed. |
| May 7 | | First growth 2 to 6 inches long. Tips dead. Blades picked from among old sheaths. |
| June 7 | | Blades 4 to 10 inches. Separated from tufts of old growth. |
| July 7 | | Growth 6 to 20 inches. Still green and succulent from continued rains. Well branched out from old stems. |
| Aug. 7 | | Growth 12 to 30 inches. No culms showing. |
| Sept. 7 | | Growth 15 to 30 inches. Culms well formed but still green. Feather-like tuftings appearing. |
| Oct. 8 | A | Full growth 15 to 36 inches. Approximately one-half green and one-half dead. Culms mature. Seeds scattering. |
| | B | Second growth, 4 to 8 inches, following mid-summer sampling. Blades approximately one-half green and succulent. No culms included. |
| | | *Danthonia spicata* from Open, Infertile, Sandy Shale Ridge, 1928 |
| May 7 | | Green leaves 1 to 3 inches long with brown tips. |
| June 7 | | Leaves 2 to 6 inches long. Not yet in head. |
| July 7 | | In head but before bloom. Leaves and culms. |
| Aug. 7 | | Seeds matured. Culms dying. |
| Sept. 7 | | Mixed first and second growth, the latter fresh, green, and tender from recent rains. |
| Oct. 8 | | Mixed first and second growth, culms dead and brown. |
| | | Orchard Grass (*Dactylis glomerata*) from Upland Orchard, 1928 |
| May 7 | | Blades 6 to 15 inches long. Green and succulent. Heading, but before bloom. |
| June 7 | | Blades and culms 6 to 24 inches. After bloom, seeds forming. |
| July 7 | | Blades and culms 10 to 30 inches. Seeds not yet ripened. |
| Aug. 7 | | Leaves and stalks 10 to 30 inches. Seeds ripened and fallen. Culms dead and brown. |
| Sept. 7 | A | Mixed first and second growth. Partly dead and brown. From open hillside. |
| | B | Second growth only, 6 to 18 inches long. No dead leaves or culms. From deep shade. |
| Oct. 8 | A | Second growth only, 6 to 24 inches. Green and succulent. From open point exposed to full sunlight throughout the day. |
| | B | Second growth only, 6 to 24 inches. Very soft and tender. From dense shade. |

rejected. An analysis of the broomsedge silage is given and compared with corresponding analyses for corn silage.

## PRESENT STUDIES

The present studies were actuated by a desire to know something more of the composition of these grasses from the standpoint of feeding value and also to learn the approximate stage at which their nutritive value begins to decline in considerable degree. Cattle and sheep seem to eat both grasses freely in the early stages of growth when the blades are green, tender, and succulent. Later, however, when the leaves and stalks become harsh and woody, they are disliked by all forms of livestock.

Throughout each of two successive seasons samples of *A. virginicus* were taken for analysis at regular intervals from plants growing in suitable locations. Samples of *D. spicata* were similarly chosen during the past season, also samples of orchard grass (*Dactylis glomerata*) from adjoining areas for purposes of comparison. The time and stage of sampling and the results of the analyses are shown in Tables 1 to 4, inclusive. Table 5 gives the results of the earlier investigations previously referred to, and Table 6 shows corresponding analyses for Kentucky bluegrass (*Poa pratensis*) and Timothy (*Phleum pratense*) as calculated from the average composition tables of Henry and Morrison (1).

TABLE 2.—*Composition of Andropogon virginicus at various stages on moisture-free basis.*

| Date collected | Crude protein % | Crude fiber % | N-free extract % | Ether extract % | Ash % | Remarks |
|---|---|---|---|---|---|---|
| | | | Open Hillside Pasture, 1927 | | | |
| May 5..... | 3.59 | 40.8 | 51.2 | 1.01 | 3.38 | Old growth (1926) |
| May 5..... | 11.71 | 27.9 | 52.4 | 2.12 | 5.83 | New growth (1927) |
| June 6..... | 13.38 | 28.6 | 47.3 | 2.79 | 7.96 | New growth (1927) |
| July 6..... | 8.56 | 33.7 | 49.2 | 2.22 | 6.35 | New growth (1927) |
| Aug. 15.... | 6.68 | 33.6 | 52.7 | 2.06 | 4.91 | No culms showing |
| Sept. 15... | 4.76 | 34.4 | 55.2 | 1.93 | 3.66 | Culms formed |
| Oct. 17.... | 4.61 | 32.9 | 56.8 | 2.15 | 3.58 | Mature |
| | | | Open Hillside Uncut Meadow, 1928 | | | |
| May 7..... | 3.96 | 35.7 | 56.9 | 1.19 | 2.19 | Old growth (1927) |
| May 7 .... | 8.31 | 23.6 | 62.9 | 1.41 | 3.73 | New growth (1928) |
| June 7..... | 12.60 | 28.0 | 51.7 | 2.53 | 5.21 | New growth (1928) |
| July 7..... | 9.55 | 31.8 | 52.2 | 2.21 | 4.28 | New growth (1928) |
| Aug. 7... . | 7.43 | 33.9 | 53.4 | 1.97 | 3.32 | No culms showing |
| Sept. 7.... | 6.15 | 32.5 | 55.8 | 2.54 | 2.98 | Culms formed |
| Oct. 8 A... | 4.32 | 33.0 | 57.4 | 2.12 | 3.16 | Mature |
| B... | 4.71 | 30.6 | 58.6 | 2.46 | 3.62 | Second growth (1928) |

TABLE 3.—*Composition of Danthonia spicata from open sandy ridge in 1928 at various stages on moisture-free basis.*

| Date collected | Crude protein % | Crude fiber % | N-free extract % | Ether extract % | Ash % | Remarks |
|---|---|---|---|---|---|---|
| May 7 | 16.90 | 23.6 | 52.1 | 2.81 | 4.54 | Early growth |
| June 7 | 11.49 | 30.2 | 50.3 | 2.97 | 4.99 | Before heading |
| July 7 | 7.35 | 33.3 | 52.9 | 3.62 | 2.82 | In head |
| Aug. 7 | 6.55 | 34.3 | 45.6 | 3.58 | 3.26 | Seeds matured |
| Sept. 7 | 7.78 | 32.8 | 50.1 | 6.08 | 3.25 | Mixed first and second growth |
| Oct. 8 | 6.61 | 31.5 | 52.6 | 5.22 | 4.08 | Mixed first and second growth |

TABLE 4.—*Composition of orchard grass (Dactylis glomerata) from upland orchard in 1928 at various stages on moisture-free basis.*

| Date collected | Crude protein % | Crude fiber % | N-free extract % | Ether extract % | Ash % | Remarks |
|---|---|---|---|---|---|---|
| May 7 | 26.42 | 18.0 | 42.6 | 4.63 | 8.34 | Heading |
| June 7 | 17.49 | 30.1 | 38.0 | 4.44 | 10.14 | After bloom |
| July 7 | 15.28 | 33.2 | 36.8 | 3.46 | 11.30 | Seeds not ripened |
| Aug. 7 | 10.77 | 35.4 | 47.6 | 2.90 | 9.96 | Mature |
| Sept. 7 A. | 8.05 | 38.2 | 45.3 | 3.32 | 5.17 | Mixed first and second growth from open |
| B. | 19.03 | 29.6 | 35.0 | 4.60 | 11.81 | Second growth only from deep shade |
| Oct. 8 A. | 10.52 | 32.2 | 46.2 | 2.96 | 8.16 | Second growth only from open |
| B. | 16.10 | 29.4 | 39.7 | 4.44 | 10.39 | Second growth only from deep shade |

TABLE 5.—*Analyses of Andropogon virginicus and Danthonia spicata previously reported on moisture-free basis.*

| Grass | Station reporting | Stage collected | Crude protein % | Crude fiber % | N-free extract % | Ether extract % | Ash % |
|---|---|---|---|---|---|---|---|
| *A. virginicus* | Mississippi | In September | 2.64 | 42.11 | 46.52 | 3.51 | 5.22 |
| *A. virginicus* | Maryland | Mature and ensiled | 5.35 | 37.30 | 49.90 | 2.38 | 5.03 |
| *D. spicata* | Maine | Full bloom | 7.49 | 34.10 | 51.74 | 2.86 | 3.81 |

TABLE 6.—*Analyses of Kentucky bluegrass and timothy at various stages on moisture-free basis.*

Calculated from tables of Henry and Morrison's "Feeds and Feeding," Ed. 18.

| Grass | Stage collected | Crude protein % | Crude fiber % | N-free extract % | Ether extract % | Ash % |
|---|---|---|---|---|---|---|
| Bluegrass | Before heading | 22.2 | 21.8 | 39.0 | 5.5 | 11.3 |
| Bluegrass | In head | 13.5 | 30.0 | 42.9 | 3.6 | 10.2 |
| Bluegrass | After bloom | 7.8 | 30.2 | 49.5 | 3.0 | 9.4 |
| Bluegrass | Ripe | 7.9 | 33.3 | 46.4 | 4.0 | 8.5 |
| Timothy | Before bloom | 10.5 | 30.3 | 48.6 | 3.5 | 7.1 |
| Timothy | Early to full bloom | 7.2 | 33.8 | 48.5 | 3.0 | 5.3 |
| Timothy | Late bloom to early seed | 6.5 | 33.3 | 51.8 | 3.3 | 5.3 |
| Timothy | Nearly ripe | 5.9 | 35.1 | 51.6 | 2.5 | 4.9 |

## DISCUSSION

A study of Table 2 shows that the early growth of *A. virginicus* is relatively high in protein and ash and that these constituents, together with the ether extract, increase appreciably during May and early June. At this time it is roughly comparable in composition to timothy and bluegrass in the heading and early bloom stages. However, fiber is also on the increase and soon after begins to reduce the relative amounts of the other constituents just named. By the end of the first week of July the blades have toughened considerably as indicated by the fiber content. From this time forward the percentages of protein and ash steadily decline until the plants have matured and turned brown and sere, while the fiber increases irregularly. The second growth (rowen) following mid-summer sampling shows a moderate reduction in fiber and slight increase in protein, ash and ether extract indicating a somewhat more nutritious character than that of the mature plants. By October, however, this also is past the desirable stage. The matured plants allowed to stand over until the following spring take on a still more woody character reaching a condition about comparable to corn husks.

As shown in Table 3, *D. spicata* starts off the season with a growth high in protein and low in fiber. It is apparently quite palatable and nutritious in the early growth stages. But the protein content decreases steadily until the plants reach maturity, while the fiber grows constantly greater. By mid-summer, maturity is attained and the grass has reached a low pasture value. Secondary growth brought on by mid-summer or early fall rains causes a slight backward swing toward better grazing value. But it seems clear that best utilization of the pasturage afforded by both of these grasses requires early grazing while they are still palatable and nutritious.

The data in Table 4 showing the composition of orchard grass at various stages and growing under various conditions are interesting. The samples were chosen from an orchard which has been either mowed or pastured yearly. The soil is similar in type to, but somewhat richer in humus than, those from which the *A. virginicus* of 1927 and the *D. spicata* of 1928 were taken. In fact the three kinds of grasses were collected, in the years mentioned, from an area with a radius not exceeding 100 yards. The protein content of the May sample of orchard grass ran so high that it was regarded as possibly in error and the analysis was repeated to insure accuracy. A second analysis gave the same result. By this time it was mid-August and too late to secure additional samples of the early growth. It was suspected that conditions of shade might be responsible, at least in

part, for the high protein character of the grass. That this was indeed the case is evidenced by the samples taken during September and October from deeply shaded areas. The September sample shows a protein content of 19% and this is still maintained at 16% well into October. The effect of shade is in agreement with the findings of Welton and Morris (5) who worked with bluegrass. Aside from the influence of shade the composition is seen to change regularly with decreasing protein and increasing fiber up to time of maturity.

## POSSIBLE UTILIZATION

The analyses reported show that *A. virginicus* and *D. spicata*, in common with other pasture grasses, are relatively high in protein content and low in fiber during their early growth. Indeed the dry matter portion of early pasture herbage in general tends toward the nature of a protein concentrate and is highly nutritious. Although adequate digestibility data for the two species under consideration are wanting, it is probable that in the early growth stages they are not markedly different from other grasses in this respect. Reasonably close and continuous grazing during May and June would utilize the plants at their time of greatest palatability and nutritive value. This type of grazing would also delay the mid-summer decline in nutritive value and reduce the high fiber character of the pasturage. In summers of favorable rainfall it might be possible to maintain the grasses in such a condition that they would be eaten by stock throughout most or all of the season.

One other point in connection with the handling of *A. virginicus* deserves consideration. The early growth of this grass for these analyses was picked by hand from the protecting sheaths and culms of the previous season's growth. This was necessary up to and including the July samples when the blades had attained a growth of 6 to 18 or 20 inches in length. These leaf blades are interspersed with, and well protected by, the tall, harsh, dead growth of the previous summer. This old growth is decidedly objectionable to all kinds of grazing animals. It is, however, almost universally permitted to stand throughout the spring following its development and frequently until it falls through decay or is broken down by the trampling of stock. The old dead growth thus prevents access of the animals to the new growth during the spring and early summer months when the latter is young, tender, and more nutritious. By the time the current season's growth extends sufficiently far beyond the old tufts to be accessible to grazing animals it is tough, fibrous, and less palatable and nutritious. From the standpoint of practical

utilization it would seem desirable, therefore, to remove the old growth close up to the crown during the fall, winter, or early spring in order to expose the new, tender growth when it comes on and thus make it accessible. Observations indicate that where this is done the growth of this grass is utilized by animals in considerably greater degree than where the matured bunches are allowed to stand.

## SUMMARY

A study of *A. virginicus* and *D. spicata* at successive growth stages indicates that:

1. The early growth of both grasses is characterized by a relatively high protein and low fiber content compared to the later growth stages.

2. Best utilization of the pasturage afforded by them involves reasonably early, close, and continuous grazing during the spring and early summer months.

3. Removing the old growth of broomsedge close to the ground previous to the appearance of the new growth will permit the grazing of the latter by livestock in considerably greater degree.

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# THE OCCURRENCE OF STRAINS RESISTANT TO LEAF RUST IN CERTAIN VARIETIES OF WHEAT[1]

C. O. JOHNSTON[2]

In recent years plant breeders and others interested in the improvement of crop plants have relied principally on the use of controlled hybridization to obtain the characters desired. Before the practical application of the Mendelian principles of heredity came into such general use considerable improvement of crops had been accomplished through selection. Many crops had been improved in yield, quality, and other agronomic characters by intelligent selection. The widespread adoption of hybridization by modern plant breeders, however, has resulted in lessening the emphasis on the older methods of crop improvement. The purpose of this paper, therefore, is to call attention to the use which has been made of selection in the production of strains of wheat resistant to a known physiologic form of leaf rust (*Puccinia triticina* Eriks., p. f. 9). The results here reported emphasize the value of that method in certain types of crop-improvement experiments.

Several investigators (1, 6, 7, 8, 9)[3] have reported the occurrence of varieties of wheat resistant to various rusts. In only a few instances, however, has it been clearly pointed out that some well-known varieties, once thought to be susceptible, contain rust-resistant strains. Varieties usually are considered as units, especially if particular care has been exercised to keep them pure, although they often contain several strains, indistinguishable morphologically, but differeing in their reaction to disease.

Mains (3) and Mains and Jackson (4) have pointed out that resistance to leaf rust in general was found in many strains of wheat of different types. They state that different strains of Turkey under such names as Turkey, Malakof, Crimean, Kharkof, and Hungarian, and also several different strains of Mediterranean, differed in their reaction to the same physiologic form of leaf rust. Kiesselbach and Peltier (2) recently reported on the occurrence of a number of pure lines of Crimean wheat differing from each other in their resistance to stem rust, *P. graminis tritici* Eriks. & Henn.

The above results differ somewhat from those presented here in which the differences in reaction to leaf rust occur within a single lot

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[3]Reference by number is to "Literature Cited," p. 573.

of wheat instead of among a number of closely related varieties. Experiments on the reaction of varieties, strains, and hybrid lines of wheat to leaf rust were started in the greenhouse at Manhattan, Kan., in 1921. These experiments were conducted to supplement studies of a like nature that were conducted in the leaf rust nursery. In the greenhouse experiments a single known physiologic form (p. f. 9) of *P. triticina* was used. This form was selected because of its wide distribution and the regularity of its occurrence in the Southern Great Plains.

Varieties and strains to be tested were grown in two-inch pots, there being approximately 30 seedlings of each variety in the first test. Further tests were made if a variety exhibited resistant strains. When the seedlings had reached the second leaf stage of growth they were heavily inoculated with leaf rust. About 14 days later each pot was examined for the presence of resistant plants. These could be distinguished easily by the absence of uredinia and the presence of whitish or yellowish flecks. In some cases a few small uredinia would be present, but they usually were surrounded by yellow necrotic areas and accompanied by flecks without uredinia.

When such resistant plants were found they were transplanted to 4-inch pots and allowed to mature. At heading time they were reinoculated to make sure they had not merely escaped infection in the seedling inoculation. Almost without exception these plants proved to be highly resistant at the time of the second inoculation. After resistant plants had been found in a variety further sowings of 100 or more seedlings were inoculated, counts made of the number of resistant and susceptible plants, and the percentage of resistant plants calculated.

The occurrence of strains differing in rust resistance within a supposedly pure variety of wheat was first noted by the writer in 1921. In testing a selection of Fulcaster, Kansas No. 55, with physiologic form 9 it was found that approximately half of the seedling plants were entirely free from that form of rust, while the remainder were completely susceptible. Several of the rust-free plants were grown to maturity in the greenhouse and used in hybridization experiments. They proved to be rust-free in all stages of growth. At heading time most of them could not be distinguished morphologically from the susceptible plants of the same variety. Two strains, however, had kernels nearly as hard as those of the hard red winter wheats, although they had the straw color and other characteristics of Fulcaster. These strains may have originated from mechanical mixtures or from natural crossing in field or nursery plats, but their presence in varieties is none the less useful as long as they breed true for their

desirable characters. All of the resistant strains which the writer thus far has isolated from varieties have bred true both for their pathologic and agronomic characters.

About 200 varieties of what have been tested for the presence of strains resistant to the physiologic form 9 since the resistant strains of Fulcaster were discovered in 1921. In some cases many different lots of the same variety, from different sources and under different accession numbers, have been tested. Each year as many new varieties and selections as can be secured, as well as different strains of varieties already used, are tested in that manner in the greenhouse. This has resulted in the discovery of strains resistant to physiologic form 9 in 28 varieties, or about 14% of the varieties tested. The varieties in which resistant strains were found and the percentage of such plants are listed in Table 1. Several of these are varieties commercially important in certain parts of the United States, or are potentially valuable because of their resistance to other plant diseases or to insect attack.

It will be noted that in some varieties nearly all of the plants were resistant, while in a few other cases only a very small percentage of resistant plants was found. In such cases it is possible that the small number of either susceptible or resistant plants is the result of mixture. If such is the case, the variety to which the mixture belongs so nearly resembles the variety with which it is mixed as to be morphologically indistinguishable. For example, Sibley, CI 5666; Golden Wave, CI 6684; Nebraska No. 28 (Awnless Sel.), Ks. 34-4; Wheedling, CI 4846; Ashland, Ks. 428; Rupert, CI 5920; Russian CI 5737; and Zimmerman, CI 6211, all had less than 3% of resistant plants, yet all of the plants had the general characteristics of the variety in which they were found. The resistant strains were not all identical with the parent variety in all morphological characters, however. Two of the strains of Fulcaster had hard kernels, while the seed of the mass variety usually is considered to be soft. Furthermore, very little is known about the strength of straw, winterhardiness, yielding ability, or milling quality of the resistant strains. They may differ from the parent varieties very markedly in one or several of these characteristics. In so far as the readily observed characteristics of the plants are concerned, however, all of them probably would pass unnoticed in fields or plats of the variety.

Nothing definite is known regarding the origin of these strains. Some of them may have originated through natural hybridization. The presence of a few slight differences within some of the selected Fulcaster strains, such as those noted in the hardness of the kernel, would seem to indicate natural crossing. In some of the varieties,

TABLE 1.—*Percentage of plants resistant to leaf rust, P. triticina, p. f. 9, in varieties of wheat tested in the greenhouse at Manhattan, Kan., 1921–1926.*

| Variety in which resistant plants occurred | Accession number* | Total number of plants tested | Resistant plants: Number | Resistant plants: % | Resistant plants: Rust class | Stem color | Glume color | Kernel characters |
|---|---|---|---|---|---|---|---|---|
| **Bearded: Soft, Red Winter** | | | | | | | | |
| Mediterranean No. 31 | | 104 | 101 | 97.1 | 0–1 | purple | brown | large, red, soft |
| Kawvale (Indiana Swamp Sel.) | CI 8180* | 112 | 105 | 93.0 | 0–1 | purple | white | midsized, red, semi-hard |
| "Diehl-Mediterranean" | Ks. 2175* | 115 | 104 | 90.4 | 0–1 | yellow | white | small, red, semi-hard |
| Silversheaf | CI 2496 | 101 | 75 | 74.2 | 0–1 | purple | white | large, red, soft |
| Kansan | Ks. 341 | 111 | 73 | 65.7 | 0–1 | purple | white | midsized, red, soft |
| Fulcaster | CI 6471 | 101 | 66 | 65.3 | 0–1 | purple | white | large, red soft |
| Fulcaster | Ks. 55 | 101 | 61 | 60.4 | 0–1 | purple | white | variable, red |
| V. P. I. 131 (Fulcaster Sel.) | Ks. 434 | 105 | 7 | 6.6 | 0–1 | purple | white | large, red, soft |
| Mammoth Red | CI 2008 | 112 | 7 | 6.2 | 1–2 | purple | white | large, red, semi-hard |
| Golden Wave | CI 6684 | 120 | 3 | 2.5 | 0–1 | purple | brown | midsized, red, semi-hard |
| Russian | CI 5737 | 104 | 2 | 1.9 | 0–1 | purple | brown | midsized, red, semi-hard |
| Sibley | CI 5666 | 160 | 2 | 1.2 | 0–1 | yellow | white | midsized, red, soft |
| **Awnless: Soft, Red Winter** | | | | | | | | |
| Illini Chief | CI 5956 | 103 | 90 | 87.3 | 0–1 | purple | brown | midsized, red, soft |
| Currell | CI 3326 | 105 | 66 | 62.8 | 0–1 | purple | brown | short, red, soft |
| Evans | CI 2946 | 108 | 54 | 50.0 | 0–1 | yellow | white | short, red, soft |
| Golden Chaff | CI 5578 | 113 | 40 | 35.4 | 0–1 | purple | brown | short, red, soft |
| Gleason | CI 6978 | 116 | 38 | 32.7 | 0–1 | purple | white | midsized, red, soft |
| Pride of Indiana | CI 5324 | 112 | 12 | 10.7 | 1–2 | purple | brown | short, red, soft |
| Shepherd | CI 6163 | 114 | 11 | 9.6 | 0–1 | purple | brown | midsized, red, soft |
| Rupert | CI 5920 | 144 | 4 | 2.7 | 0–1 | yellow | brown | midsized, red, soft |
| Nebraska No. 28 (Awnless Sel.) | Ks. 34–4 | 153 | 3 | 1.9 | 2 | yellow | white | midsized, red, soft |
| Zimmerman | CI 6211 | 150 | 3 | 2.0 | 0–1 | yellow | white | midsized, red, soft |
| Wheedling | CI 4846 | 150 | 3 | 2.0 | 2 | purple | brown | midsized, red, soft |
| Ashland | Ks. 428 | 134 | 2 | 1.5 | 2 | purple | white | midsized, red, soft |
| **Spring Wheats** | | | | | | | | |
| Kofod | CI 4337 | 110 | 16 | 14.5 | 1–2 | yellow | brown | midsized, white, soft |
| Hard Federation | CI 4733 | 109 | 7 | 6.4 | 0–1 | yellow | brown | short, white, hard |
| Resaca | CI 6390 | 108 | 4 | 3.7 | 1–2 | purple | brown | short, red, soft |

such as Shepherd (Ks. 435), rust-free, highly resistant, slightly resistant, and susceptible plants were found. In most of the varieties, the resistant plants were rust-free (class O) or highly resistant (class 1–2). While no cases of segregation were noted in the next generation after selection, a careful study was not made of this point and a thorough search might reveal evidences of previous crossing. If this were the case, the $F_1$ and part of the plants in each subsequent generation would be heterozygous. The heterozygotes would appear not as resistant, but as susceptible plants, however, for susceptibility to physiologic form 9 usually is dominant (5). In this case all rust-resistant strains arising through natural crossing would be homozygous recessive segregates of $F_2$ or later generations.

It will be noted that all but three of the varieties listed in Table 1 are soft red winter wheats. Hard Federation is a hard white spring variety, Kofod is a soft white winter wheat intermediate in growth habit, and Reseca is a soft red spring wheat. Kofod usually is winter-killed at Manhattan, but succeeds from spring sowing and therefore is listed as a spring variety in Table 1. Turkey, Kanred, Kharkof, Beloglina, Altera, and several other hard red winter varieties were tested, as were also Marquis, Kota, and other hard red spring wheats. All varieties of both these groups proved to be homogeneous in their reaction to p. f. 9 of *P. triticina* in the seedling stage. Most of them were completely susceptible, although some exhibited a slight resistance (class 2–3). All plants of the variety behaved in the same manner, however, and therefore they are not listed in Table 1. The absence of rust-resistant strains in the hard red winter and hard red spring classes may be due principally to the smaller number of varieties of those classes available for testing and to the fact that only one form of rust was used.

If several forms of rust had been employed, resistant strains doubtless would have been found among the hard red winter and hard red spring wheats, for Mains (3) already has noted their presence. Strains resistant to any one physiologic form probably would not be resistant to all of the other 11 known physiologic forms of leaf rust, however. Some of the strains resistant to form 9 have been tested with physiologic form 5 and most of them have proved to be completely susceptible to that form. Physiologic form 9 is the most prevalent form of leaf rust in the Southern Great Plains, however, and the resistance of the greenhouse-selected strains when grown in the rust nurseries proves the usefulness of the method discussed in this paper.

Rust-resistant selections also may be resistant to other diseases. Mains (5) noted that certain varieties of wheat which are resistant

to some of the physiologic forms of leaf rust also are resistant to one or more other important diseases, such as stem rust, powdery mildew, bunt, and scab. Shepherd is resistant to rosette and flag smut in the Mississippi Valley and Illini Chief is highly resistant to Hessian fly attack in the Southern Great Plains. Most of the leaf-rust-resistant strains have not been sufficiently tested for agronomic qualities to justify a report on that phase here, but some of them are known to be promising. One of the principal values of the selections made in these studies, however, was to supply rust resistant strains with known varietal characteristics as parental stock for crossing.

## SUMMARY

In studies on the reaction of varieties of wheat to leaf rust, *P. triticina*, p. f. 9, in the greenhouse at Manhattan, Kan., 28 out of about 200 varieties were found to contain resistant strains.

With but few exceptions the resistant strains resembled the varieties from which they came in their general morphological characters. Some of them varied slightly from the parent varieties in one or more characters, such as kernel texture.

Most of the varieties in which resistant strains were found are soft red winter wheats.

These studies have shown that selection within varieties of wheat is a useful method of quickly securing strains which are resistant to a single physiologic form of leaf rust.

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# THE VALUE OF SUPPLEMENTARY BACTERIA FOR LEGUMES[1]

J. K. Wilson and E. W. Leland[2]

## INTRODUCTION

Over 40 years ago it was observed that the transfer of a small quantity of soil from a well-established legume field to a field that was being planted to the legume for the first time may make a difference between failure and success of the crop. The explanation of this lay in the fact that by such a transfer of soil there were distributed the legume bacteria which are required by the host plant. This procedure has been practiced to a considerable extent, but often the inconvenience of securing such soil and the danger of transferring disease-producing organisms, as well as undesirable weed seeds, have led to the development and the use of artificial cultures, or commercial cultures, of the desired bacteria.

The artificial culture method has, therefore, very largely supplanted the soil transfer method. The ease with which these cultures may be procured, together with the desire of the manufacturer to sell as many cultures as possible, has resulted in the recommendation and in a considerable use of such cultures not only on land that has never grown the legume but also on fields that have grown the legume consecutively for 10 years or more. This has been practiced on a commercial scale with such a crop as canning peas. The value of this practice on fields that have been previously inoculated or are known to contain the desired organism has been questioned, especially with such crops as red clover, alfalfa, etc. It has been assumed that once a field was thoroughly inoculated with the desired organism it would survive so that maximum nodulation would occur on subsequent crops, and that the addition of more bacteria at seedtime was unnecessary. The practical and scientific point in this connection is whether or not soil will maintain under various cropping conditions from year to year or longer the legume bacteria in sufficient numbers to meet the requirements of young plants.

Deherain (2),[3] after making a study of the distribution of bacteria throughout the soil, believed that abundance of bacteria may be carried by wind, etc., to all soils and that artificial cultures are unnecessary. Albrecht (1) stated that soils once inoculated for soybeans and red clover did not need to be reinoculated when these

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[3]Reference by number is to "Literature Cited," p. 586.

crops were grown in a four-year rotation. Also, Pieters (4) is of the opinion that failure of red clover was not due to the absence of the proper bacteria, because when alsike clover was grown on the soils where red clover had failed there was an abundance of nodules.

More recent studies by Whiting (5), however, have shown that as a result of inoculation with artificial cultures there was a considerable improvement in the growth of peas in an acid silt loam, which had not grown peas for 11 years. On examining plants from the inoculated portion every one had nodules, while on that part of the field where the plants were dependent on the legume bacteria which the soil normally supported nodules were present only on occasional plants. Other benefits of supplementing the legume bacteria of the soil were taller vines, greater yield of vines and protein content, and a larger percentage of No. 1 and No. 2 grades of peas.

From a study of the effect on nodulation of supplementing the legume bacteria of the soil with artificial cultures, Wilson (6) concluded that soils may be or may become an unfavorable habitat for the various groups of legume bacteria, that the bacteria may largely or entirely disappear from the soil, that this disappearance occurs in proportion to the increase in acidity of the soil, that the bacteria do not seem to be greatly influenced by the frequency of the host plant in the rotation, and that in acid soils the addition of more bacteria resulted in the formation of a larger number of nodules per plant.

In a subsequent study of the legume bacteria population of the soil Wilson (7) reported that as much as 5 grams of soil with a reaction of pH 5.4, which had been inoculated five years previously, did not contain the bacteria capable of producing nodules on alfalfa, while another field of the same soil with pH 5.4 contained more than 100,000 bacteria per gram that were capable of producing nodules on soybeans.

The soil reaction and its relation to certain types of the legume bacteria was pointed out by Hiltner (3) who maintained that liming a soil either injured or rendered inactive the lupine bacteria.

From the observations recorded above one may conclude that certain crops may be benefited by a supplementary application at seedtime of the proper legume bacteria while certain others may not, depending upon the specific type of bacteria and the reaction of the soil. In case there is response to such an application of bacteria it should be reflected in some observation, such as an increase in numbers or quantity of nodules, and this effect in turn should be reflected in a thicker and more enduring stand, in greater yields, and

in the vigorous appearance of the plants. It is hoped that the following experimental evidence from field trials will throw some light on the value of supplementary bacteria for legumes.

## PROCEDURE

The soil on which this test was conducted consisted of plats 751 to 762 which are 12 one-thousandth acre in size. They were used from 1917 to 1925 in a study of the effect of crops on nitrates. Plats 751, 752, 753, 757, 758, and 759 were limed. The other six were unlimed. During this period plats 751 to 756 were plowed late in the fall, while plats 757 to 762 were plowed about May 1. All plats were kept bare until about the middle of July, at which time each year they were planted as follows: 751, 754, 757, and 760 to rye; 752, 755, 758, and 761 to vetch; and 753, 756, 759, and 762 to oats. The crops were never removed but were plowed under as indicated above. In 1926, corn and, in 1927, oats were grown on all the plats and the crops removed. The yields from these two crops indicated that the soil on comparable plats was fairly uniform. In the fall of 1927 all plats were plowed and sown to wheat. The following spring the wheat was plowed under and the soil harrowed as soon as it could be worked. At this time the present experiment was started, the object being to study the value of supplementary bacteria for legumes.

The general plan of the experiment was to have one area with only the bacteria present which the soil naturally supported and another with those bacteria naturally present supplemented with artificial cultures distributed with the seed. It was desired to have this condition both on the limed and unlimed areas. Also, information concerning the value of supplementary bacteria was desired for beans, peas, red clover, and alfalfa on both the limed and unlimed areas. To accomplish this, and at the same time to avoid the possible influence of the previous crops on the results that may be obtained, each plat was divided into four small plats, the area of each being 0.003 acre. This permitted the growing of each legume on each of the larger plats and made it possible to grow each crop on a limed and unlimed area both with the bacteria present which the soil naturally supported and with these organisms plus artificial cultures. Fig. 1 shows the detailed arrangement of the experiment.

A study of the legume bacteria population of the plats in this test was made in 1926 (7). It was determined at that time that all these plats contained at least a spattering of the legume bacteria for each of the crops which were grown in this test. In order to supplement those organisms that the soil naturally supported, the following

method was pursued. Some of the growth from an agar slope of the desired organism was mixed with water. This formed a bacterial suspension, which was added to sterile soil. At seedtime, which was about two weeks later, some of the soil was mixed with the seed. The seed was then sown by hand, either in rows for such seeds as peas and beans or broadcast for such seeds as red clover and alfalfa, the former being lightly covered with a hoe and the latter lightly raked in.

## EXPERIMENTAL

### SUPPLEMENTARY BACTERIA FOR ALFALFA (*Medicago sativa*)

On April 20, 1928, 41 grams of alfalfa seed were sown on each 0.003 acre plat indicated in Fig. 1. The total number of plants per acre which started and which survived was determined. The number of plants bearing nodules and the average per 100 plants, as well as

| 751 | 752 | 753 | | 754 | 755 | 756 |
|---|---|---|---|---|---|---|
| R E | D | K I D | N E Y | B | E A N | S |
| | F I | E L D | P E | A S | | |
| | A | L F | A L F | A | | |
| | R E | D | C L O | V E | R | |

Limed Unlimed
Bacteria Supplemented

| 757 | 758 | 759 | | 760 | 761 | 762 |
|---|---|---|---|---|---|---|
| R E | D | K I D | N E Y | B | E A N | S |
| | F I | E L D | P E | A S | | |
| | A | L F | A L F | A | | |
| | R E | D | C L O | V E | R | |

Limed Unlimed
Bacteria Not Supplemented

FIG. 1.—Detailed arrangement of plats 751 to 762. Each plat was divided into four small plats, the area of each being 0.003 acre.

the weight of the oven-dry crop, were determined. These results are shown in Table 1.

TABLE 1.—*Supplementary bacteria for alfalfa.*

| Treatment | Plat No. | Reaction of soil, pH | Number plants per acre, June 8 | Number nodules per 100 plants, June 13 | Number plants, July 25 | Weight oven-dry crop, July 25, pounds per acre | Number plants, Sept. 10 |
|---|---|---|---|---|---|---|---|
| | | | Limed Plats | | | | |
| Not supplied | 757 | 7.42 | 3,392,000 | | | 2,305 | |
| with bacteria | 758 | 7.57 | 3,620,000 | 403 | —* | 2,058 | —* |
| | 759 | 7.68 | 3,540,000 | | | 2,089 | |
| Limed plats, | 751 | 7.60 | 4,104,000 | | | 2,623 | |
| bacteria | 752 | 7.59 | 2,768,000 | 399 | —* | 2,367 | —* |
| supplied | 753 | 7.68 | 3,524,000 | | | 2,169 | |
| Increase: Pounds | | | | | | 707 | |
| Per cent | | | | | | 10.9 | |
| | | | Unlimed Plats | | | | |
| Bacteria not | 760 | 5.34 | 3,436,000 | | 1,732,000 | 217 | 190,000 |
| supplied | 761 | 5.84 | 2,900,000 | 8 | 1,644,000 | 229 | 248,000 |
| | 762 | 5.24 | 3,338,000 | | 1,400,000 | 119 | 36,000 |
| Bacteria | 754 | 5.37 | 2,700,000 | | 2,144,000 | 255 | 568,000 |
| supplied | 755 | 5.30 | 3,280,000 | 21 | 2,940,000 | 233 | 504,000 |
| | 756 | 5.30 | 2,924,000 | | 1,664,000 | 179 | 154,000 |
| Increase: Pounds | | | | | | 102 | |
| Per cent | | | | | | 18 | |

*Not determined.

The results indicate that on limed soil there was no increase in the number of nodules that could be attributed to supplementary bacteria. The plants grew so well on all six plats that no attempt was made to determine the number of alfalfa plants that survived. There was shown, however, an increase of about 11% in the oven-dry crop from those plats which received supplementary bacteria.

On the unlimed soil, the reaction of which was about pH 5.3, the figures indicate a very large increase in nodulation. A comparison of yields and of nodulation of plants from the limed and the unlimed areas indicates that some other factor than the deficiency of the proper legume bacteria was necessary before alfalfa would be successful on the unlimed area. There was only one-thirteenth as much dry material produced on the unlimed as there was on the limed soil. Supplementing the bacteria which the acid soil normally supported with an artificial culture not only increased the oven-dry weight of the crop 18%, but also carried a larger number of plants through the season. The yields from these acid soil plats, however, were not

large enough to be of much interest from a practical point of view. On June 8 there were about 3 million plants per acre on all plats. On July 25, on the unlimed, non-bacterial-supplemented plats, there were about 1.5 million plants per acre, while on the bacteria supplemented plats there were about 2.3 million plants. On September 10 the difference was more pronounced, indicating that on the acre basis supplementing the legume bacteria caused the survival of several hundred thousand plants that otherwise would have died.

On the unlimed plats that did not receive supplementary bacteria about 8% of the plants which were present in June had nodules on their roots, and about this same percentage of plants survived to September 10. Also, about 21% of the plants on the unlimed plats which did have the bacteria supplemented produced nodules, and about 12.5% of the plants which were present in June survived to September 10. If the entire crop from the six plats which did not receive supplementary bacteria is compared with the entire crop from the six which did receive treatment, there is an increase of 11.5% in favor of supplementary bacteria treatment. However,

TABLE 2.—*Supplementary bacteria for red clover.*

| Treatment | Plat No. | Number nodules per 100 plants, June 13 | Oven-dry crop in pounds per acre, July 25 |
|---|---|---|---|
| | Limed Plats* | | |
| | 757 | | 985 |
| Bacteria not supplemented | 758 | 1,329 | 1,105 |
| | 759 | | 1,365 |
| Average | | | 1,151.6 |
| | 751 | | 1,273 |
| Bacteria supplemented | 752 | 1,193 | 1,322 |
| | 753 | | 2,239 |
| Average | | | 1,611.3 |
| Increase, % | | | 39.9 |
| | Unlimed Plats | | |
| | 760 | | 1,061 |
| Bacteria not supplemented | 761 | 593 | 881 |
| | 762 | | 347 |
| Average | | | 766 |
| | 754 | | 1,111 |
| Bacteria supplemented | 755 | 618 | 872 |
| | 756 | | 1,058 |
| Average | | | 1,013.6 |
| Increase, % | | | 32.2 |
| Increase: 6 plats bacteria supplemented over 6 not supplemented | | | 2,131 |
| Per cent | | | 37.09 |

*For reaction of these plats see Table 1.

there was a much larger actual increase on the limed land than on the unlimed areas.

### SUPPLEMENTARY BACTERIA FOR RED CLOVER (*Trifolium pratense*)

On April 20, 27.5 grams of red clover seed were sown on each 0.003 acre plat indicated in Fig. 1. On June 13 the number of nodules on 100 plants was counted, and on July 25 the crop was cut and oven-dry weights obtained. The data from this test are presented in Table 2.

An inspection of Table 2 indicates that supplementing the legume bacteria with an artificial culture has not increased appreciably the number of nodules on plants which grew either on the limed or unlimed plats, although the oven-dry crop indicates an increase of 39.9% on the limed area and 32.2% on the unlimed area. If the six untreated plats are compared with the six treated, there is an increase of over 37% in oven-dry crop in favor of supplementary bacterial treatment.

### SUPPLEMENTARY BACTERIA FOR KIDNEY BEANS (*Phaseolus* sp.)

Red kidney beans were planted June 12 at the rate of 72 seeds every 12 feet of row. The beans were pulled September 10 to 17. Oven-dry weights of total crop and of hulled beans were obtained. The data are shown in Table 3.

Supplementary legume bacteria for red kidney beans on well-limed soil showed an increase of 1,657 pounds, or 12.8%, of oven-dry crop per acre. The increase in shelled beans was 539 pounds per acre, equal to 9.2%. The effect of such a treatment on acid soil, however, was not so pronounced. There was practically no increase in dry weight of whole crop and a slight loss of shelled beans, but whether this loss is significant or not it is difficult to say because of the small number of plats in the experiment. If the six plats, representing both the limed and unlimed soil, receiving supplementary bacteria are compared with those not receiving such treatment, the increase in dry weight of the whole crop was 1,695 pounds per acre, or 9.2%. If such a a comparison is made with figures of shelled beans, there was an increase of 381 pounds per acre, or 4.98%. The nodules on bean roots came off so easily when the plant roots were being freed from earth that no nodule count was obtained.

TABLE 3.—*Supplementary bacteria for red kidney beans.*

| Treatment | Plat No. | Dry weight in pounds per acre, whole crop | Dry weight in pounds per acre, beans |
|---|---|---|---|
| | Limed Plats* | | |
| | 757 | 4,340 | 1,637 |
| Bacteria not supplemented | 758 | 4,130 | 1,960 |
| | 759 | 4,400 | 2,220 |
| Average | | 4,290 | 1,939 |
| | 751 | 4,897 | 2,093 |
| Bacteria supplemented | 752 | 4,983 | 2,210 |
| | 753 | 4,647 | 2,053 |
| Average | | 4,632.3 | 2,118.6 |
| Increase: due to supplementing bacteria: Weight | | 1,657 | 539 |
| Per cent | | 12.8 | 9.2 |
| | Unlimed Plats | | |
| | 760 | 2,123 | 697 |
| Bacteria not supplemented | 761 | 1,853 | 617 |
| | 762 | 1,503 | 507 |
| Average | | 1,826.3 | 607 |
| | 754 | 1,680 | 467 |
| Bacteria supplemented | 755 | 1,887 | 573 |
| | 756 | 1,950 | 623 |
| Average | | 1,839 | 555.6 |
| Increase due to supplementing bacteria | | 38 | —158 |

*For reaction of these plats see Table 1.

SUPPLEMENTARY BACTERIA FOR PEAS (*Pisum arvensi*)

Seed for this test was sown April 19 in rows 21.8 inches apart. Thirty grams of seed were used for each 12 feet of row. Nodule counts on plants from the various plats were made June 15, and on July 12 photographs of plant roots and nodules were obtained. On August 3 the crop from the unlimed plats was taken and on August 7 that from the limed plats was taken. The peas at this time were dead ripe and began shattering a little when handled. The effect of supplementing the legume bacteria which the soil naturally supported with an artificial culture is shown in Figs. 2, 3, and 4, and in Table 4.

The results indicate very strongly that on alkaline soil the addition of more legume bacteria at seedtime for peas has materially reduced the number of infections per plant. On the limed portion, where the bacteria naturally occurring in the soil were relied upon to effect nodulation, there were an average of 35.6 nodules per plant, while on the plats which had those bacteria naturally present supplemented with an artificial culture there were only 28 nodules per plant.

Such data might lead one to question the value of supplementary bacteria, but an inspection of Figs. 2, 3, and 4 will indicate a quite

FIG. 2.—Pea plant roots showing nodules.
Grown in slightly alkaline soil without supplementary bacteria. Average of 58 nodules per plant.

different conclusion. All the photographs were made on the same day. Fig. 2 was made from plant roots taken from the limed plats which did not have the bacteria supplemented. Attention is called

FIG. 3.—Pea plant roots showing nodules.
Grown in slightly alkaline soil with supplementary bacteria. Average of 49 nodules per plant.

to the numerous small nodules. Fig. 3 was made from plant roots taken from the limed area where the bacteria naturally occurring were supplemented with an artificial culture. Note the size and location of the nodules on the roots in this figure in comparison with those in Fig. 2. Fig. 4 shows the nodules from the roots shown in Figs. 2 and 3. No one would hesitate to say that the quantity of nodules produced where supplementary bacteria were applied through the addition of artificial cultures is not materially larger than that produced on like soil where no such supplementary treatment was used.

TABLE 4.—*Supplementary bacteria for peas.*

| Treatment | Plat No. | Number nodules per 12 plants | Oven-dry weight whole crop in pounds per acre | Weight dried peas in pounds per acre | Gain % |
|---|---|---|---|---|---|
| | | Limed Plats* | | | |
| | 757 | 425 | 2,677 | 470 | |
| Bacteria not supplied | 758 | 377 | 2,650 | 553 | |
| | 759 | 481 | 3,360 | 887 | |
| | 751 | 262 | 3,663 | 977 | |
| Bacteria supplied | 752 | 361 | 3,090 | 707 | |
| | 753 | 386 | 3,253 | 910 | |
| Gain, 3 plats | | —274 | 1,319 | 684 | |
| Gain in crop | | | | | 15.1 |
| Gain in dried peas | | | | | 35.8 |
| | | Unlimed Plats | | | |
| | 760 | 322 | 3,557 | 1,170 | |
| Bacteria not supplied | 761 | 291 | 3,460 | 1,253 | |
| | 762 | 302 | 2,427 | 1,017 | |
| | 754 | 326 | 3,510 | 1,373 | |
| Bacteria supplied | 755 | 437 | 3,543 | 1,390 | |
| | 756 | 576 | 3,723 | 1,563 | |
| Gain, 3 plats | | 424 | 1,332 | 886 | |
| Gain in crop | | | | | 14.0 |
| Gain in dried peas | | | | | 25.7 |
| Total gain | | | 2,651 | 1,570 | |
| Gain in total crop | | | | | 14.3 |
| Gain total crop, dried peas | | | | | 29.3 |

*For reaction of these plats see Table 1.

These plant roots and nodules were 57 days old when photographed. It is believed that if the plant roots had been examined at the end of three or four weeks there would have been more nodules per plant where the bacteria were supplemented. The basis for this lies in a study (6) that was made in 1926 of the effect of supplementary bacteria on nodule production. In this study it was evident that supplementing the legume bacteria which the soil from certain of these plats naturally supported with an artificial culture increased the number of nodules on vetch plants which were grown only 21

days. It might be of interest to state that the number of legume bacteria for vetch as determined at that time on certain of these limed plats was at least 100,000 per gram of soil.

The results from the unlimed plats are also very striking as regards nodulation. Supplementing the natural legume bacteria with an artificial culture increased the number of nodules from 25.4 per plant to 37.1. Not only was the number of nodules larger but also the quantity was very materially increased. This was very easily recognized by their size and location on the roots. They resembled in every respect those nodules on the plant roots which grew on the

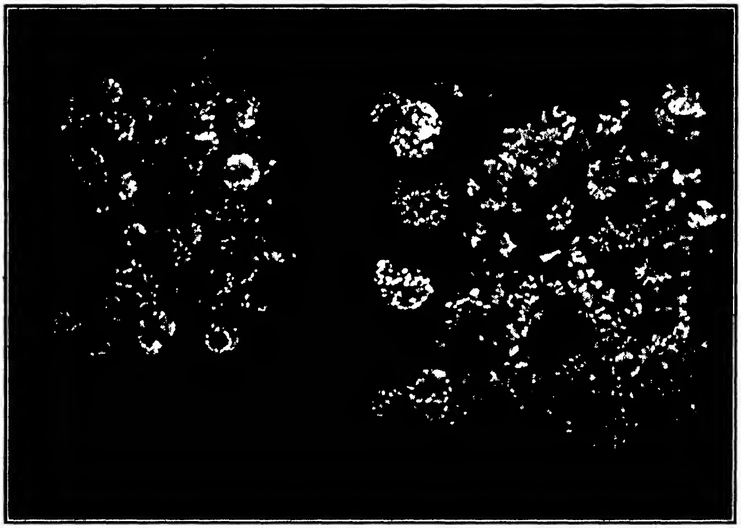

FIG. 4.—Pea plant nodules.
On left, from plants shown in Fig. 2; on right, from plants shown in Fig. 3.

limed soil whose photograph is shown in Fig. 3. It is believed that this increase of nodules per plant on the acid soil is due to the fact that the soil of the acid plats did not support a sufficient bacteria population to produce the best nodulation and growth of peas. The number of legume bacteria in the soil from certain of these acid plats which were able to produce nodules on vetch as determined in September 1926 was about 1,000 per gram.

The total yields from the limed and unlimed plats are also very striking. It is noted that the yields of both the whole crop and of the dried peas were considerably increased on the limed plats which received supplementary bacteria, being 15.1% and 35.8%, respectively. The whole crop from the unlimed plats which received supplementary bacteria was 14% larger than that from similar

plats not receiving supplementary bacteria. The gain in dried peas was 25.7%.

It is also of interest to compare the yield of dried peas from the six limed plats with that from the six unlimed plats. Over 70% more dried peas were obtained from the plats whose pH was about 5.3 in contrast with that from the plats whose pH was about 7.3. The yield of total dry crop, however, is not very different, being 8.1% in favor of the unlimed areas.

If the total crop yields from the six plats which received no bacteria are compared with those from the six plats receiving supplementary bacteria there is an increase of 14.3% in favor of the latter. Such a comparison of the total crop of dried peas also shows an increase of 29.3% in favor of supplementary bacteria.

## SUMMARY

Experiments have been conducted to determine the value of supplementing the legume bacteria which the soil naturally supports with an artificial culture for alfalfa, red clover, beans, and peas. Limed and unlimed field plats, representing only one type of soil, have been used. Yields from one season only are presented. A few points may be emphasized.

Alfalfa which was grown on limed soil produced about 11% more dry weight when supplementary bacteria were applied at seedtime, although roots 46 days old failed to indicate any value of the extra bacteria as measured by the number of nodules. Supplementing the legume bacteria on the unlimed soil which had a pH of 5.3 produced an increase over the plats not receiving such a treatment not only in the number of nodules and in the dry weight of the crop, the latter being equal to 18%, but also in the number of plants that survived throughout the season, this being equal to several hundred thousand plants per acre.

Red clover which was grown on limed and unlimed soils produced 39.9% and 32.2% more dry weight, respectively, when supplementary bacteria were applied at seedtime.

Red kidney beans which were grown on the limed plats showed an increase of 12.8% in oven-dry crop and 9.2% in shelled beans per acre in favor of supplementary legume bacteria. On the acid plats there was a slight gain of total dry crop and a slight decrease in shelled beans where the artificial culture was used. An average of both total crop and of shelled beans from the six plats receiving the supplementary bacteria compared with that from the six not receiving such treatment shows an increase of only 9.2% in total crop and 4.98% in shelled beans in favor of supplementary bacteria.

Peas which were grown on both limed and unlimed plats had a larger quantity of nodules on their roots than plants from similar plats which did not receive supplementary bacteria. The total crop and the dried peas from these plats were also considerably larger, being 15.1% and 35.8% greater in total crop and 14% and 25.7% greater in dried peas, respectively, than those from similar plats not receiving supplementary bacteria. The total yield from the six plats which received supplementary bacteria was 14.3% larger than the total yields from the six plats not so treated. In dried peas it was 29.3% in favor of supplementary bacteria.

## CONCLUSION

Although results for only one season have been obtained relative to the value of supplementary legume bacteria for certain legumes on field plats, it is believed that the plat yields, together with the results of previous studies concerning the legume bacteria in the soils of these plats which have extended over three seasons and have been published elsewhere, may indicate that a more general use of artificial cultures to supplement the legume bacteria which the soil naturally supports can profitably be used, even though the soil may contain a considerable number of the proper legume organisms.

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# AGRONOMIC AFFAIRS

## NEWS ITEMS

A. R. Midgley, who completes graduate work for a doctor's degree at the University of Wisconsin in June, will enter upon an appointment as Research Professor of Agronomy at the University of Vermont in July. He will conduct investigations primarily on pasture fertilization and the availability of fertilizer materials.

R. W. Thatcher, President of Massachusetts Agricultural College, has been named an advisor to the United States Trust Company of New York City in the

management of the Herman Frasch Foundation funds for research in the field of agricultural chemistry. The appointment was made on the recommendation of the American Chemical Society.

DAVID A. SAVAGE, Assistant Agronomist in charge of Cooperative forage crop investigations at the Judith Basin Branch Station, Moccasin, Montana, resigned effective April 1 to accept appointment to a similar position at the Fort Hays Experiment Station in Kansas.

W. O. WHITCOMB, Superintendent of the Montana Grain Inspection Laboratory, has completed a year of graduate study at the University of Minnesota, majoring in plant breeding. W. D. Hay, Seed Analyst of the Laboratory, was Acting Superintendent during the absence of Mr. Whitcomb.

JOHN P. LEWIS, Assistant, Montana Grain Inspection Laboratory, in charge of protein testing, has resigned to enter commercial work in Nebraska. Harold E. Tower, a 1928 graduate in agronomy from Montana State College, has been appointed as Mr. Lewis' successor.

ONE of the outstanding features of the Annual County Agent Conference held at Bozeman during February, 1929, was a joint conference of the agronomic workers with the county agents. The leading research projects in agronomy were discussed by representative of the agronomy staff of the home station and of three branch stations to make available recent information and developments that might be useful to the county agents. Likewise, the county agents explained their outstanding problems and pointed out in what ways certain research projects could be modified to best serve their needs as county agents.

J. G. LIPMAN was asked by Secretary Jardine to serve on the National Committee on Soil Erosion and on the Advisory Council of the Allegheny Forest Station. Other members of the Committee on Soil Erosion include Dr. A. G. McCall and Director A. B. Conner of the Texas Experiment Station.

F. C. GERRETSEN, member of the staff of the Groningen Experiment Station, Holland, came to the New Jersey Experiment Station on January 15 to devote six months to special work on soil organic matter.

S. A. WAKSMAN, microbiologist of the New Jersey Experiment Station has been given leave of absence to attend several meetings in Europe this summer. He will meet with other members of the International Committee on Soil Organic Matter at Budapest on July 1, attending at the same time the preliminary meetings of the Second International Congress of Soil Science. On July 25 he will attend a meeting of the Third Commission at Stockholm, as well as the meetings of the International Congress of Forest Experiment Stations.

A SUCCESSFUL short course in turf management was held at New Brunswick, N. J., during February under the auspices of Rutgers University. It lasted one week and was attended by 54 persons, including greenskeepers, members of greens committees, park superintendents, and commercial men. The subjects included soils as related to turf management, seed mixtures and seed testing, and turf pests and their control. The course was organized by the Department of Agronomy and the faculty consisted of ten members of the Agricultural College staff.

LINWOOD L. LEE of Rutgers University and the New Jersey Agricultural Experiment Station has reported for duty at the Rothamsted Station, in accordance with an exchange arrangement supported by the International Education Board. Professor Lee is in contact with the county organizers, and is acquainting them with the methods used in conducting and interpreting soil surveys. G. W. Scott Blair is to report for duty at the New Jersey Station as representative of the Rothamsted Station on the exchange arrangement.

A North Dakota Crop Improvement Association was organized on January 17, 1929 at the Agricultural College at Fargo. A total of 142 delegates, representing 42 of the 53 counties in the state, were present at the organization meeting. R. H. Points of Crosby was elected President; O. W. Hagen of Watford City, Secretary and Treasurer; and Jeff Baldwin of Oberon, Vice-President. These three men together, with Professor H. L. Bolley and Dr. E. G. Booth of the Agricultural College, J. H. Gebracht, Chantapeta, and August Cordes, of Douglas, constitute the Board of Directors. This Association made provision for a State Advisory Seed Board, consisting of representatives of the organized seed trade, of the Crop Improvement Association, of the Pure Seed Laboratory, and of the Agricultural College.

A special three-day seed growers' school was held at the North Dakota Agricultural College, January 17 to 19 and was attended by approximately 150 seed growers of the state.

R. G. Shands, a graduate student at the University of Wisconsin and who will receive his Ph.D. degree in June, has been appointed Assistant Agronomist in the Wisconsin Agricultural Experiment Station, effective April 1. Mr. Shands will be concerned chiefly with grain breeding investigations.

Gustav Geiszler, assistant in the Field Husbandry Department of the University of Saskatchewan, has resigned in order to take a position as farm loan inspector for the North American Life Insurance Company with headquarters at Saskatoon. Mr. Geiszler will have for his territory the central part of Saskatchewan.

Manley Champlin, senior professor of field husbandry, University of Saskatchewan, was re-elected Vice-president of the International Crop Improvement Association at the last annual meeting of that organization in Chicago.

L. E. Kirk of the University of Saskatchewan reports excellent progress with the new forage plant which was selected from the seed production field of Arctic sweet clover. This plant has some characteristics which remind one of alfalfa, but it is a biennial and is being thoroughly investigated as to its hardiness and other properties, with a view to using it for a rotation clover in the northern prairies. The number of family lines has been reduced to two, which are coming true to type, and it is expected that this number will be further reduced to one during the present season. The new crop has not been named as yet. It is being tested at several of the Canadian and northern United States experimental farms but has not yet been given to the public.

Merrill Oveson, teaching fellow in soils in the Oregon Agricultural College during the past five terms, has completed residence requirements for the master's degree, and has been appointed Assistant Agronomist at the Oregon institution.

The fourth annual conference of tobacco research workers of the Connecticut and Massachusetts Experiment Stations met at New Haven, April 4. Progress reports on investigations under way were made and plans for the immediate future were discussed.

The Massachusetts Experiment Station has enetered into a cooperative agreement with the Office of Forage Crops, Bureau of Plant Industry, U. S. Dept. of Agriculture, for testing the adaptability of regional strains of legumes. Seedings of alfalfa strains were made last year and this year seedlings of strains of red clover, field peas, soybeans, and additional strains of alfalfa will be made.

A. L. Hafenrichter of the Department of Botany, Baker University, Baldwin, Kansas, has recently been elected Assistant Professor in Farm Crops in the Department of Agronomy at the State College of Washington. He will devote his time largely to investigational work with forage crops and will assume his new duties June 15.

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## SYMPOSIUM ON "PASTURE MANAGEMENT RESEARCH"

### FOREWORD

The program which this group of papers represents was formulated by the New England Section of the American Society of Agronomy. It was developed on the basis of most of the programs of the Section of recent years, namely, that of bringing together workers in related fields, all having a mutual interest in a special topic. In this case, farm management specialists, economists, animal nutrition specialists, agronomists, and others came together for a day and focussed their attention on the big problem of pasture management research. If such a gathering serves no other useful purpose than that of promoting acquaintanceship and good fellowship, it is probably justified. Add to that, the assembling of an extensive lot of subject matter and the publication of it, as in this special number of the JOURNAL, and the symposium becomes quite worth while. This appears to be the first time a comprehensive symposium devoted entirely to the subject of pasture management research has been held in this country.—A. B. BEAUMONT, *Leader*.

## 1. COMPARATIVE RETURNS IN FEED UNITS FROM CROP ROTATION AND PASTURE[1]

J. W. WHITE[2]

Pasture improvement studies of northeastern agricultural experiment stations have dealt largely with the rejuvenation of old pastures of extensive acreage in an attempt to stimulate the growth of existing grasses which vary in species and nutritive value in accordance with the particular soil conditions. Little attention has been given to the development of highly productive Kentucky bluegrass pastures on land similar to that now occupied by cultivated crops.

Lack of knowledge concerning the economic value of intensive pasturage has been responsible for the general belief that the more fertile type of farm land can be utilized to better advantage in a

[1]Paper read as part of the symposium on "Pasture Management Research" presented at the joint session of the New England Section of the Society and Section O of the A. A. A. S. held in New York City, December 28, 1928.

[2]Professor of Soil Technology, Pennsylvania State College, State College, Pa.

rotation system. Field plat studies conducted at the Pennsylvania Experiment Station since 1916 and dealing with the development of Kentucky bluegrass pastures on three widely different soil types have furnished data which indicate that highly developed Kentucky bluegrass pastures are worthy of a more prominent place in the economic scheme of farm management.

The farmers of Pennsylvania, especially those in the southern half of the state, have for many years followed a four-year grain rotation of corn, oats, wheat, and hay ("Dutch Rotation") and have fully realized the economic feeding value of such a cropping system. At the same time the grazing land, embracing 4,500,000 acres including 1,700,000 acres of plowable land, has been neglected due to lack of definite information concerning the possible feeding value of intensive pasturage. It is of utmost importance, therefore, to emphasize the value of highly developed pastures by studying the feeding values of the two systems of soil management when conducted simultaneously on the same soils by using a similar system of fertilization. Such experiments have been in progress under the supervision of the author since 1916. The details of these experiments have been published in Bulletin 195 of the Pennsylvania Experiment Station and need not be reviewed in detail at this time.

In presenting the data gained from these studies it is fully recognized that such data would have a far greater significance were the results secured by actual feeding or grazing experiments. Such means of measurement, however, are exceedingly difficult under the conditions of pasture feeding experiments due to the difficulty of determining the maintenance requirements of grazing animals and many other factors fully realized by those who are now conducting such experiments. The studies of the Connecticut, Massachusetts, and Pennsylvania Experiment Stations dealing with extensive grazing experiments will no doubt furnish data of great scientific value concerning the actual carrying capacity of variously treated areas.

The Pennsylvania data presented in this paper are secured by computing the digestible nutrients as suggested in Henry and Morrison's "Feeds and Feeding" supplied by green immature pasture grasses containing 76.2% water and the air-dry products of a four-year grain rotation of corn, oats, wheat, and hay. The pasture grasses include, for the most part, Kentucky bluegrass and relatively small yields of red top and sweet clover. The grain rotation nutrients are computed to include (1) the entire products and (2) excluding oats and wheat straw or nutrients available for cattle feeding. The field weight of crops, or air-dry matter, is also included. The results of four representative fertilizer and manure treatments are included in this paper in case of each of the two cropping systems. The nature and rate in pounds per acre of manurial treatments, applied biennially, are as follows: 65 pounds phosphoric acid in superphosphate (P), 50 pounds potash ($K_2O$) in muriate of potash (K), 48 pounds nitrogen (N) in nitrate of soda, 6 tons farm manure (M) reinforced with 180 pounds 16% superphosphate on Volusia and Westmoreland soil and 4 tons of manure reinforced with 280 pounds of superphosphate on

DeKalb soil. Each treatment is applied to limed soil. The feed units or digestible nutrients include, in case of each cropping system, digestible crude protein and total digestible nutrients produced per acre in excess of the untreated soil. The data in Table 1 were secured on each of the three soils.

TABLE 1.—*Average annual production in pounds per acre of feed units (digestible nutrients) in excess of untreated soil.*

| Plat treatment | Pasture: Air-dry matter | Pasture: Total digestible nutrients | Pasture: Digestible crude protein | Grain rotation*: Air-dry matter | Grain rotation*: Total digestible nutrients (A) | Grain rotation*: Total digestible nutrients (B) | Grain rotation*: Digestible crude protein (A) | Grain rotation*: Digestible crude protein (B) |
|---|---|---|---|---|---|---|---|---|
| De Kalb Soil, Snow Shoe Experiment Fields, 1917–24 | | | | | | | | |
| P | 2,497 | 1,338 | 310 | 2,047 | 1,131 | 935 | 97 | 93 |
| PK | 3,155 | 1,673 | 388 | 2,792 | 1,553 | 1,311 | 131 | 128 |
| PKN | 3,898 | 2,084 | 483 | 3,140 | 1,728 | 1,393 | 142 | 135 |
| MP | 3,003 | 1,606 | 372 | 3,135 | 2,173 | 1,843 | 144 | 138 |
| Average | 3,141 | 1,675 | 388 | 2,779 | 1,646 | 1,371 | 129 | 124 |
| Volusia Soil, Bradford County Experiment Fields, 1919–26 | | | | | | | | |
| P | 1,386 | 1,002 | 211 | 1,095 | 1,046 | 949 | 94 | 92 |
| PK | 2,167 | 1,420 | 304 | 2,271 | 1,763 | 1,611 | 159 | 156 |
| PKN | 2,835 | 1,882 | 415 | 2,273 | 1,892 | 1,379 | 161 | 156 |
| MP | 2,555 | 1,759 | 386 | 2,189 | 1,829 | 1,585 | 160 | 155 |
| Average | 2,236 | 1,516 | 329 | 1,957 | 1,633 | 1,381 | 144 | 140 |
| Westmoreland Soil, Washington County Experiment Fields, 1919–26 | | | | | | | | |
| P | 1,866 | 952 | 174 | 1,550 | 861 | 679 | 69 | 65 |
| PK | 2,151 | 1,163 | 239 | 1,791 | 1,052 | 829 | 83 | 78 |
| PKN | 3,597 | 1,865 | 411 | 2,158 | 1,169 | 843 | 89 | 82 |
| MP | 3,840 | 1,974 | 436 | 2,277 | 1,240 | 1,003 | 101 | 96 |
| Average | 2,774 | 1,489 | 315 | 1,945 | 1,081 | 839 | 83 | 81 |
| General Average of the Three Soils | | | | | | | | |
| P | 1,916 | 1,097 | 232 | 1,564 | 1,013 | 854 | 87 | 83 |
| PK | 2,491 | 1,419 | 310 | 2,285 | 1,456 | 1,251 | 124 | 121 |
| PKN | 3,443 | 1,944 | 436 | 2,524 | 1,596 | 1,205 | 131 | 124 |
| MP | 3,133 | 1,779 | 398 | 2,534 | 1,747 | 1,477 | 135 | 130 |
| Average | 2,746 | 1,560 | 344 | 2,477 | 1,453 | 1,197 | 119 | 115 |

*(A) including all products; (B) excluding oats and wheat straw.

A study of Table 1 shows that, with the exception of the manured plat on DeKalb soil and the PK treatment on Volusia soil, the pasture land has produced a greater yield of air-dry matter, or field weight of crops, than was produced in the grain rotation. The total digestible nutrients produced on the DeKalb and Westmoreland pastures exceed that of the grain rotation in case of each treatment, with the exception of the manured DeKalb soil. On Volusia soil the production of total digestible nutrients on the rotation plats exceeds that of the pasture land in case of each of the four treatments. The production of digestible crude protein, however, is greater on the pasture land in case of every treatment of the three soils.

The summary data show that the pasture, as a general average, has produced 10.9% greater weight of air-dry matter, 7.4% more total digestible nutrients, and 189% more digestible crude protein than was produced in the grain rotation.

A study of the comparative values of the several treatments in the production of feed units in the two cropping systems shows that potash has caused an increase of 29% of nutrients on the pasture

compared to 43% in case of the grain rotation. Nitrogen, however, has increased the nutrients in the pasture land 37% and in the rotation system only 6%. The PKN treatment has given 9% increase in nutrients on pasture in excess of the reinforced manure. However, the manure treatment has been 9% more effective than PKN in case of the grain rotation. Even though soluble nitrogen has caused an increase of 37% over PK in growth of pasture grasses, its effectiveness would no doubt have been much greater had it been applied annually or even semi-annually.

To produce a four-year grain rotation (Lancaster County, Pa.) on 4 acres yielding 61 bushels of corn, 3,166 pounds of stover, 33.3 bushels of oats, 1,500 pounds of oats straw, 28.3 bushels of wheat, 2,725 pounds of wheat straw, and 3,200 pounds of hay requires 226 hours of man labor and horse labor at a total cost of $59.61. To maintain the same acreage in permanent pasture would involve not more than 8 hours of man labor and horse labor at an annual cost of $2.80.

Such a rotation would yield on 4 acres a total of 799 pounds of digestible crude protein and 10,096 pounds of total digestible nutrients (including the nutrients in straw) as compared with 1,986 and 8,535 pounds, respectively, produced on 4 acres of pasture where complete fertilizers were used.

Labor economy of pasture feeding is emphasized by the fact that to produce 1 ton of digestible crude protein in the grain rotation involves a labor cost of approximately $178.00 as compared with $2.82 on pasture.

Four acres of ensilage corn (Lancaster County, Pa.) yielding 37.2 tons would produce 744 pounds digestible crude protein and 9,896 pounds total digestible nutrients at a labor cost of $106.04. The labor cost per ton of total digestible nutrients would be $21.21 as compared with $0.66 on pasture.

The above data serve to emphasize the economic importance of pasture feeding as compared with a system of grain rotation and seem to justify the use of land for highly productive pastures similar to that now used for cultivated crops.

## DISCUSSION

The Pennsylvania experiments have demonstrated rather conclusively that fertilizer investments on grazing lands may yield equal or superior returns, in terms of digestible nutrients, to similar investments on rotated crops. These findings are in harmony with those of other workers who have recently observed that pasture grasses are highly efficient, relative to most crop plants, in their ability to recover and utilize fertilizer additions. This seems to be especially true for applications of nitrogenous fertilizers, increases in crude protein in the vegetation indicating complete recovery of the nitrogen added having been reported from both Ohio and Massachusetts. Considering the fact that there is associated with this high efficiency in the utilization of fertilizer additions a minimum cost of harvesting the increase through grazing, it seems obvious that applications of fertilizers to grass land may be made with a high degree of economy.

It is readily agreed that there exist many opportunities for the practical application of this principle in areas of intensive livestock and dairy production. On the other hand, there may be reason to doubt the conclusion that the failure of farmers in southern Pennsylvania to improve their 4,500,000 acres of grazing

land is due to the "lack of definite information concerning the possible feeding value of intensive pasturage." Other factors than the relative returns from fertilizer investments on pasture and cropped land may be expected to influence the farmer's attitude toward pasture improvement.

The southeastern quarter of the state of Ohio comprises an area of residual non-limestone soils, for the most part hill land devoted to general livestock production, quite typical of extensive areas in the states to the east and south of the Ohio River.

There are in this quarter of the state roughly 3 million acres of permanent pasture, mostly of poor quality, as indicated by a seasonal grazing capacity of one animal unit for each 5 to 8 acres. In this region there have been established, since 1920, nearly 1,000 pasture improvement demonstrations designed to show the profit from limestone and superphosphate treatment. On many of these, areas of treated and untreated pasture have been caged for harvest and analysis. Actual grazing experiments have been conducted in a few cases. This work has been accompanied by a vigorous educational campaign through the medium of field meetings, tours, newspaper publicity, and the other tools of the extension worker. The demonstrations themselves have been surprisingly successful, indicating increases in pasturage of from 100 to as high as 400%, and leaving no doubt as to the economy of the treatments. Yet today, we find relatively few farmers who have adopted the practice of treating their pastures, while the total area of grazing land thus improved is as yet insignificant. Aside from the difficulty of financing even moderate investments in fertility on such low acre-value land there are undoubtedly other economic factors that have prevented the adoption of practices which appear fundamentally sound.

The system of farming followed, especially as it affects the relative needs for grain feeds and pasture, is certainly an important factor. The general system in this region is for farmers to produce their own calves or lambs, grow them on pasture, and finish them with grain produced on the farm. The beef cattle farmer, for example, maintains his cow herd, runs his cows with their calves on grass during the summer and finishes his calves in the fall and winter on grain, usually sending them to market as baby beef weighing around 1,000 pounds. The cows are commonly wintered on silage. For such a system, with assumed yields of corn of 31½ bushels per acre, the 10-year average for 11 typical southeastern Ohio counties, and an assumed capacity for grazing land of one animal unit for each 6½ acres, a proper ratio between pasture land and land cropped to corn would be 4:1. As a matter of fact, in spite of the farmer's tendency to put as much of his tillable land in corn as is practically possible, the actual ratio between the acreage of pasture and land in corn for these 11 typical counties is about 7.7:1.

In other words, the beef cattle farmer in this region finds that the extent of his business is limited by the amount of corn he can grow rather than by a lack of sufficient pasturage. It is perhaps logical that he should continue to devote most of his attention to the improvement of his tillable land rather than to treating his pasture, in spite of the high theoretical returns from the latter practice.

It is possible that systems of farming might and should be modified to take advantage of the opportunities for profit in pasture treatment. Practically, however, changes of this kind are made slowly, if at all. It seems probable, therefore, that in those extensive grazing areas in the eastern states, of which southeastern Ohio is a fair example, the improvement of pasture land by fertilizer treatment is not likely to develop at a rapid rate. On the other hand, in the areas of intensive dairy production, such as surround many of our larger cities, the writer sees no logical impediment to the rather general adoption of such pasture improvement practices.—ROBT. M. SALTER, *Ohio Agr. Exp. Station.*

## 2. INCOME FROM CROP AND PASTURE LAND[1]

E. G. MISNER[2]

The use of land for crops and pasture has been summarized (1)[3] in the 1923 Yearbook of the U. S. Department of Agriculture. The object of this paper is to present some facts regarding the income and outgo connected with pasture and crop land for the purpose of arriving at a clearer understanding as to whether pasture land is receiving the attention that its economic importance deserves.

Three areas have been chosen for an inquiry into costs and incomes from pasture, *viz.*, the northeastern dairy region of the United States as represented by New York conditions, the tame grass pastures of Minnesota and the Dakotas, and England.

### COST OF MAINTAINING PASTURE

In 1915, the cost of maintaining 7,928 acres of Broome County, N. Y., pasture was 7.1% of its value of $20.25 per acre. In 1919, the costs for 14,765 acres of Herkimer County pasture was 7.6% of its value of $38.77 an acre. Slightly over 3 acres were pastured per animal unit. For the five-year period, 1923–25, the average cost of maintaining pastures on New York farms keeping careful cost accounts in cooperation with the New York State College of Agriculture was 8.3% of the value of $24.72 an acre. In computing these charges interest was 5% and taxes and other costs 2.1 to 3.3% of the value of the pasture land. Thus interest comprises from two-thirds to three-fourths of the cost of maintaining pasture. The cost account pastures carried an animal unit for each 2.1 acres.

Minnesota reported (2) the cost of maintaining tame-grass pasture in 1907 on 8 farms as $4.063 per acre. One and one-fourth acres were required for the full feed for a 1,000-pound animal. Data on costs of pasture maintenance for other areas are not at hand.

In 1919, in England the cost of grazing 976 acres on 12 farms amounted to $16.78 an acre, or $23.99 per cow per year. The land carried an equivalent of one cow to 1.43 acres, about the same as the Minnesota pasture and twice as many as the New York pastures. The grazing period was 22 weeks. This is $1.09 per cow per week (3), or 15.6 cents per cow per day.

These three sets of data (Table 1) give a range in cost of maintaining pasture per acre of from $1.45 in Broome County, N. Y., to $16.78 per acre in England in 1919 at the height of the post-war period.

### INCOME FROM PASTURE LAND

The difference between the cost of feeding animals on pasture and of feeding animals in the barn is seldom fully realized. In six areas of New York State, the cost of pasture, the cost of winter feed, and the returns from the milk per cow per day were as shown in Table 2.

[1]Paper read as part of the symposium on "Pasture Management Research" presented at the joint session of the New England Section of the Society and Section O of the A. A. A. S. held in New York City, December 28, 1928.

[2]Professor of Farm Management, Cornell University, Ithaca, N. Y.

[3]Reference by number is to "Literature Cited," p. 603.

TABLE 1.—*Costs of maintaining pasture land in New York and in England.*

| Charges | Cost per acre | Percentage of value | Cost per animal unit pastured |
|---|---|---|---|
| Broome County, N. Y., 1915 | | | |
| Interest | $1.02 | 5.0 | $3.15 |
| Taxes | 0.10 | 0.5 | 0.32 |
| Other costs | 0.33 | 1.6 | 1.03 |
| Total | $1.45 | 7.1 | $4.50 |
| Herkimer County, N. Y., 1919 | | | |
| Interest | $1.94 | 5.0 | $5.89 |
| Taxes | 0.31 | 0.8 | 0.95 |
| Other costs | 0.70 | 1.8 | 2.12 |
| Total | $2.95 | 7.6 | $8.96 |
| New York Cost Account Farms, 1923–27 | | | |
| Interest | $1.24 | 5.0 | $2.58 |
| Taxes | 0.46 | 1.9 | 0.96 |
| Other costs | 0.35 | 1.4 | 0.74 |
| Total | $2.05 | 8.3 | $4.28 |
| England, 1919, 12 Farms, 976 Acres | | | |
| Rent | $6.11 | | |
| Rates (taxes) | 1.65 | | |
| Seed | 0.18 | | |
| Manure | 4.47 | | |
| Incidentals | 1.86 | | |
| Labor: | | | |
| Man | 1.67 | | |
| Horse | 0.84 | | |
| Total | $16.78 | | |

TABLE 2.—*Cost of and returns from pasture in New York compared with winter feeding.**

| County | Year ending April 30 | Cost of pasture per cow Per season | Cost of pasture per cow Per day | Cost of feed used supplementary to pasture per cow per day | Total cost of pasture and feed used supplementary to pasture per cow per day | Returns from milk per cow per day in pasture period | Cost of winter feed per cow per day | Returns from milk per cow per day in winter |
|---|---|---|---|---|---|---|---|---|
| Broome | 1915 | $4.54 | $.028 | $.019 | $.047 | $.24 | $.25 | $.25 |
| Herkimer | 1919 | 10.97 | .065 | .036 | .101 | .47 | .48 | .39 |
| Chenango | 1922 | 7.10 | .043 | .038 | .081 | .30 | .39 | .29 |
| Cortland† | 1922 | 10.05 | .065 | .094 | .159 | .40 | .43 | .50 |
| Madison | 1922 | 9.15 | .058 | .060 | .118 | .35 | .44 | .43 |
| Jefferson | 1922 | 10.11 | .063 | .012 | .075 | .29 | .28 | .17 |
| Average | | $8.65 | $.054 | $.043 | $.097 | $.34 | $.38 | $.34 |

*Misner, E. G. Cornell Univ. Agr. Exp. Sta. Buls. 409, 421, 432, 433, 438, 441, 442, 452, 455, and 462.

†This area produced Grade A milk for which premiums were paid, so the returns are higher than in other areas.

The average date of turning out to pasture in these areas was May 14 and of stabling in the fall October 22, allowing a grazing period of 161 days.

The nutriment furnished by pasture per cow per day on the basis of the nutriment used per unit of product in winter for 149 farms in Broome County, N. Y., amounts to 16 therms, 18 feed units, or 18 pounds of digestible nutrients (4).

The average cost of pasturing a cow in these areas was \$8.65 for the season, or 5.4 cents per day. The cost of feed used supplementary to pasture averaged 4.3 cents per cow per day. The total cost of pasture feed was 9.7 cents per cow per day. The returns for milk in the same period averaged 34 cents per cow per day.

In the winter period the value of feed used averaged 38 cents per cow per day and the returns from milk sold, 34 cents per cow per day.

The average value of milk sold in the winter period for the four years, 1921–24, on some Chenango County farms was \$1,763 per farm. The cost of concentrates used per farm was \$792; the value of hay and other dry forage, \$531; and the value of silage and other succulent feed, \$444; giving a total of \$1,767, or \$4 more per farm than the value of the milk produced. Thus, the value of the milk produced in winter did not quite pay for the feed used, leaving no return for labor, interest, depreciation, use of buildings, and all the other costs incidental to milk production. If the dairy farmer were to buy hay and silage at farm prices, as well as concentrates for his cows, he would be compelled to quit the production of winter milk, unless he could make enough on the milk produced in summer to justify his continuing in business.

The value of milk sold during the pasture period averaged for the same four years \$1,062 per farm. The value of pasture used was \$171 and of feed used supplementary to pasture \$207, making a total value of pasture feed \$378 per farm. Thus, the milk produced in the pasture period exceeded the value of the pasture feed used by \$684 per farm. This allowed for all other costs and some pay for labor, but did not make up for the loss in winter.

Under present conditions of cheap pasture land, very high priced farm labor, a relatively low price for milk in winter, and a low selling price for hay, the incentive for dairymen to shift over to winter production is not particularly strong.

The average returns from 81,683 acres of pasture land on 1,134 New York farms, when the value of feed used supplementary to pasture and the value of labor on cows during the pasture period are deducted from the value of milk produced during the pasture period, was \$849 per farm or \$11.37 per acre of pasture (Table 3).

TABLE 3.—*Returns from pasture in several New York dairy regions with labor and supplementary feed deducted from milk receipts.*

| Region | Year | Number of farms | Acres of pasture | Returns Per farm | Returns Per acre of pasture |
|---|---|---|---|---|---|
| Broome | 1915 | 149 | 7,928 | \$379 | \$7.12 |
| Herkimer | 1919 | 163 | 14,765 | 1,918 | 21.17 |
| Chenango, Grade B | 1921 | 121 | 9,016 | 726 | 9.74 |
| Chenango, Grade B | 1922 | 88 | 5,892 | 629 | 9.39 |
| Chenango, Grade B | 1923 | 95 | 7,406 | 882 | 11.31 |
| Condensery, Norwich | 1921 | 83 | 7,233 | 798 | 9.16 |
| Oxford, Grade A | 1921 | 84 | 7,506 | 1,211 | 13.55 |
| Tully & Homer, Grade A | 1921 | 51 | 3,550 | 820 | 11.78 |
| Munnsville, alfalfa | 1921 | 125 | 6,997 | 669 | 11.96 |
| Munnsville, alfalfa | 1922 | 108 | 6,629 | 638 | 10.40 |
| Cheese factory, LaFargeville | 1921 | 67 | 4,761 | 671 | 9.45 |
| **Totals and averages** | | **1,134** | **81,683** | **\$849** | **\$11.37** |

In one region, Broome County, where all of the pasture costs were found and deducted from the value of milk produced on pasture, the gain from cows then was \$3.34 per acre of pasture land. This was in addition to the appreciation on young cattle grazing the pasture, which was \$1.22 an acre of pasture, making a total of approximately \$4.56 an acre returned from pasture above all costs. The average value of pasture land in this area was \$20.25 per acre, thus making the returns something like 22.4% on the value. Obviously, this method of calculation favors pasture in a manner which can not be definitely determined because some of the winter feed was used to get cows in condition for summer production. Pasture thus receives credit for some of the winter expense. By this method of figuring in a strictly summer dairy section, pasture would show a gain decidedly larger than stated; but even making some allowance for unfair credit, pasture is such a productive feed and so cheap that the returns from its use make the value of pasture land appear to be under-estimated.

Another type of return from pasture is the gains made by beef cattle from grazing. North Dakota reports from 28 to 82 pounds of beef produced per acre on some experimental pastures grazed in 1923 and 1924. Some were undergrazed and some decidedly overgrazed (5). In this region, where the normal rainfall for the year was 17 inches, with straight grazing of an entire field for the whole season, it was found that 7 acres were required to the two-year-old steer (6).

In the summer of 1922, the gain on pasture made by 7,549 cattle in England was 261 pounds per animal (7). The September, 1922, average price to farmers of first and second quality Shorthorn cattle in England was \$12.18 per 100 pounds (8). The acreage required to pasture an animal in England was not stated; but if taken at the same as required to pasture a cow (1.4 acres, stated previously), the gross return per acre of pasture would then be \$22.65.

In 1907, the gains for 75 yearlings and two-year-olds on pasture in Minnesota averaged 272 pounds; the gains on 42 calves, 183 pounds; the average of all being 240 pounds per head, or much the same as in England (2). With 1.25 acres required per animal, the returns from 240 pounds of gain at \$4.80 per 100 pounds, the September, 1922, farm prices of beef cattle in Minnesota, would be \$9.22 an acre.

In 1922, the wholesale price level of all commodities stood at 159% of pre-war in England and at 152% in the United States. The purchasing power of the farm price of beef cattle was 100 in England and 70 in the United States. Thus, to make the returns per acre more nearly comparable, the figure for England should be 70% of \$22.65, or \$15.86 an acre.

## COST OF MAINTAINING CROP LAND

In 1923–27, on New York farms keeping cost accounts in cooperation with Dr. G. F. Warren, for crop land valued at \$76 per acre, the annual charge for maintaining crop land averaged 7.6% of its value, 5% for interest and 2.6% for all other expenses. This is \$5.77 per

acre. The data are given in Table 4. The annual cost of maintaining an acre of crop land in percentage of its value is about the same as of maintaining an acre of pasture, but crop land is valued at from two to four times pasture land, hence the per acre charge is correspondingly more.

TABLE 4.—*Maintenance costs of crop land, orchard, and drains, New York cost account farms, 1923–27.*

| | Average Per farm per year | Per acre |
|---|---|---|
| Number of accounts | 115 | |
| Total acres | 120.9 | |
| Inventory (crop land, orchards, and drains) | $9,194.28 | $76.05 |
| Percentage of farm value | 43.5 | |
| Costs: | | |
| Interest at 5% of value | $459.72 | $3.80 |
| Taxes and share of overhead | 179.67 | 1.49 |
| Depreciation | 7.55 | 0.06 |
| All else | 3.44 | 0.03 |
| Labor:* | | |
| Man | 34.02 | 0.28 |
| Horse | 7.51 | 0.06 |
| Equipment use | 5.86 | 0.05 |
| Total cost | $697.77 | $5.77 |
| Annual cost in percentage of value | 7.6 | |

*For removal of stones, stumps, and brush; repairs to tile drains; cleaning ditches; etc.

## INCOME FROM CROP LAND

The average cost of producing various crops and the value of the products per acre for New York cost account farms are given in Table 5. The weighted average cost of the crops indicated, which includes most of the crops grown on these farms, was about $40 an acre and the returns $41 an acre. Silage was valued at cost. While the weighted average gain was about $1 per acre, if one had grown an equal acreage of the crops indicated the loss would have been $1 per acre.

TABLE 5.—*Income from crop land, 1923–27, New York cost account farms.*

| Crop | Cost per acre | Value of crop per acre | Gain per acre | Loss per acre | Returns per hour of labor |
|---|---|---|---|---|---|
| Alfalfa | $ 31.81 | $ 37.71 | $5.90 | —— | $ .77 |
| Apples | 103.37 | 112.61 | 9.24 | —— | .63 |
| Barley | 32.84 | 28.31 | —— | $4.53 | —.10 |
| Beans | 44.44 | 21.34 | —— | 23.10 | —.49 |
| Buckwheat | 26.76 | 16.08 | —— | 10.68 | —.21 |
| Cabbage | 98.03 | 78.65 | —— | 19.38 | .21 |
| Corn for grain | 66.89 | 35.91 | —— | 30.98 | —.17 |
| Corn silage | 59.77 | | Credited at cost | | |
| Hay | 21.81 | 19.81 | —— | 2.00 | .17 |
| Oats | 35.50 | 27.12 | —— | 8.38 | —.04 |
| Potatoes | 120.73 | 178.02 | 57.29 | —— | 1.10 |
| Wheat | 41.37 | 36.98 | —— | 4.39 | .23 |
| Weighted average | $39.97 | $40.58 | $0.606 | | |

When all costs excluding labor are included it appears that the general run of crops in New York returned about 40 cents an hour for time on these farms for the period 1923–27. From either the

standpoint of return on the investment or return for time, pasture land is more remunerative than crop land, especially on farms where no intensive cultivated cash crops are grown, but both must be used together in climates such as ours.

In a dairy region where cash crops, such as cabbage and potatoes, are grown, when the crops are weighted in proportion to the acreages grown in that region, the gain per acre above costs on crop land would be $1.45 an acre. Corn for the silo comprised 18% of the acreage, oats and other spring grain 26%, alfalfa 12%, other hay 30%, cabbage 6%, and potatoes 8% of the acreage grown.

## PASTURE IMPROVEMENT ECONOMICS

Some farmers are so situated that the cheapest way to improve their pasture is to buy a farm either adjoining or in close proximity to use exclusively for pasture purposes. The time to buy these farms is at hand, before those best suited for this purpose have been devoted to reforestation or inflated in value because of re-occurring agricultural prosperity.

Sometimes such farms have sets of buildings which may appear to need repairs but on which repairs would not pay. In appraising farms in this condition, one should be careful not to let the discouragingly ragged appearance of buildings overshadow the value of the land for pasture purposes. The land may be worth the price if the buildings are allowed to fall down. On some dairy farms where there are building facilities for more cows and where some of the land at present pastured would make good crop land, the pasturing of more distant land would be a decided advantage. It is in such cases that the adding on of sub-marginal farms for pasture purposes would pay most. As the demand for fluid milk increases, the tendency will be to concentrate on the production of more fall and winter milk in the better locations. In so doing there will be more cows dry during the summer that can be turned away to pasture. Careful consideration should be given to plans for devoting the better adapted of such marginal farms in the state to this purpose.

Second to the purchase of pasture land the next cheapest way of obtaining more pasturage is to improve one's own pasture. Improvement of pasture has been delayed on many farms because of the pressure of more important farm work. On others, there is much rough land pasture on which it would not pay to spend time or money. In slack times on some farms it would pay to cut brush and thorn apples, burn brakes and tree trimmings, ditch some of the marshes, drag run out areas, and scatter some seed. On some night pastures the application of manure would pay. Usually pastures are so rough in the northeastern dairy belt of the United States that it would be impractical to apply manure on them thinly with the spreader. In many pastures Canada thistle and other weeds are gaining footholds. The spread of these weeds is so rapid that unless pastures are mowed the seed is soon spread over a considerable area. On many northeastern farms, the cutting of weeds and brush are two phases of the pasture management problem that require im-

mediate attention. As they are mostly labor tasks, these are improvements which require very little cash outlay. Every dairy farmer should feel the urge to do as much of such work as possible.

The application of manure to old pastures is a second type of pasture improvement involving no great cash expenditure. In the northeastern dairy region crop land is limited and manure is plentiful on most dairy farms. From experimental results it appears that the greater value of the increased crops for each ton of manure used is obtained when applications are relatively light and that with each additional ton added after a light application, the returns diminish. But in dairy regions, because of the small amount of crop land, much heavier applications than would permit of most efficient use of manure are made. To cover the crop land with a heavy application once in each rotation is generally the practice. Whether the application to pasture land of some of the manure would not pay better than to apply so much of it to crop land, is a question deserving serious study on such farms.

If it is considered that animals void at the same rate during the pasture period as during the winter, cost of bedding is deducted and allowance made for some summer manure reaching the crop land, then the manure produced on the pasture would amount to approximately 2.0 tons per acre on New York dairy farms where about twice this amount is applied to crop land. The distribution of manure directly on pasture land is not most effective and much of the benefits that would be derived from this application are lost.

So little manure is applied to pastures in New York that no idea can be formed of the economic advantages of the practice by a comparison of those that do and do not follow the practice. However, we are beginning to collect some information concerning the use of manure on crop land. The writer obtained the information as to the use of manure on Chenango County, N. Y., dairy farms for five consecutive years 1921–25. For these farms a study has been made of the variation in crop yields resulting with varying applications of manure (9).

On the farms studied 33% of the manure was applied directly to corn for the silo, 8% to cabbage, 44% to mixed hay, and 15% to land used for other crops. Four tons were available annually per acre of crops grown. Manure applied to mixed hay on these farms gave a greater percentage increase in yield per ton of manure than the same application on cabbage or corn for the silo. Twice as much manure was required to produce a given percentage increase in yield of cabbage as of hay, but the value of cabbage was four times that of hay. Thus, the application of manure to cabbage ground was profitable. Corn for the silo was grown on much land manured the previous year and hence did not respond greatly to direct applications of manure. When manure is applied on hay land, the yield of the subsequent crop is increased. The results of varying rates of manure application on hay, corn for the silo, and cabbage are shown in Table 6. The value of manure when applied to different crops is shown in Table 7.

TABLE 6.—*Rates of manure application on mixed hay, corn silage, and cabbage.*

| Tons of manure per acre | Number of records | Percentage of manure on Mixed hay | Percentage of manure on Corn silage | Percentage of manure on Cabbage | Commercial fertilizer per acre Corn silage | Commercial fertilizer per acre Cabbage | Tons per acre Mixed hay | Tons per acre Corn silage | Tons per acre Cabbage | Tons of manure per Crop acre | Tons of manure per Farm |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Mixed Hay | | | | | | |
| 0.0 | 71 | 0 | 61 | 12 | $2.41 | $7.21 | 1.6 | 11.5 | 9.4 | 3.3 | 192 |
| 2.0 | 164 | 36 | 42 | 8 | 2.63 | 8.00 | 1.6 | 11.0 | 9.5 | 3.1 | 196 |
| 4.7 | 130 | 54 | 27 | 9 | 2.68 | 8.67 | 1.8 | 11.9 | 11.6 | 4.1 | 271 |
| 9.4 | 140 | 56 | 21 | 7 | 2.97 | 8.05 | 2.2 | 12.4 | 10.4 | 5.0 | 307 |
| | | | | | Corn Silage | | | | | | |
| 0.0 | 81 | 62 | 0 | 11 | 3.75 | 8.65 | 1.7 | 11.9 | 10.3 | 3.6 | 238 |
| 5.8 | 117 | 52 | 23 | 12 | 2.95 | 8.27 | 1.8 | 11.2 | 10.6 | 3.7 | 252 |
| 11.2 | 134 | 39 | 40 | 7 | 2.26 | 6.79 | 1.8 | 11.8 | 10.1 | 4.3 | 246 |
| 18.4 | 140 | 28 | 56 | 5 | 2.27 | 8.22 | 1.8 | 12.2 | 10.5 | 4.3 | 265 |
| | | | | | Cabbage | | | | | | |
| 0.0 | 140 | 49 | 41 | 0 | 2.10 | 7.55 | 1.8 | 11.8 | 9.2 | 3.7 | 226 |
| 8.4 | 98 | 44 | 26 | 12 | 3.19 | 7.47 | 1.9 | 11.9 | 9.6 | 3.9 | 245 |
| 13.0 | 71 | 42 | 26 | 19 | 3.60 | 8.71 | 1.8 | 11.7 | 11.1 | 3.9 | 251 |
| 19.8 | 60 | 35 | 30 | 20 | 3.79 | 8.95 | 2.0 | 12.1 | 12.6 | 4.7 | 324 |
| Average | | 44 | 33 | 8 | $2.71 | $8.02 | 1.8 | 11.8 | 10.3 | 4.0 | 246 |

TABLE 7.—*Value of manure per ton applied to different crops.*

| | Corn silage: No manure directly on corn | Corn silage: Manure directly on corn | Mixed hay: No manure directly on hay | Mixed hay: Manure directly on hay | Cabbage: No manure directly on cabbage | Cabbage: Manure directly on cabbage |
|---|---|---|---|---|---|---|
| Number of farms | 81 | 391 | 71 | 434 | 140 | 229 |
| Manure per acre, tons | 0 | 11,70 | 0 | 4.45 | 0 | 12.63 |
| Yield per acre, tons | 11.88 | 11.73 | 1.54 | 1.78 | 9.23 | 10.80 |
| Value of crop per ton | $6.00 | $6.00 | $16.00 | $16.00 | $12.00 | $12.00 |
| Value of crop per acre | $71.28 | $70.38 | $26.24 | $28.48 | $110.76 | $129.60 |
| Commercial fertilizer per acre | $3.75 | $2.50 | 0 | 0 | $7.56 | $8.24 |
| Value of crop per acre less fertilizer cost | $67.53 | $67.88 | $26.24 | $28.48 | $103.20 | $121.36 |
| Difference in value per acre due to manure | —— | $0.35 | —— | $2.24 | —— | $18.16 |

From this it appears that one of the best places to apply manure is on hay land. Better yields of hay and other crops and equally good yields of corn for the silo are obtained on dairy farms where more of the manure is applied to meadows. This suggests that the use of more manure on hay land would increase the forage crops grown on dairy farms. Also, it suggests that on farms where the topography and the distance of the pasture did not make it impractical, the benefits from manuring pasture, both in the increased amount of pasturage resulting and in the improvement in the kind of plants that would come in, would be profitable.

Other types of pasture improvement, such as the application of fertilizer or lime, require the expenditure of more money. Since the cost of pasture is so exceedingly low, $8.65 a cow a season in New York, any such treatment of pasture land would greatly increase the relative cost. For example application of one-half ton of lime per acre at a cost of $5 per acre would treble the cost of pasturing an acre.

From May to September, inclusive, in 1928, the price of 3.4% milk to producers at Utica was $2.31 per 100 pounds. The four-year average production during the pasture period in one region of New York was 16.4 pounds per cow per day (10). The value of this production at 1928 prices would therefore be 38 cents per cow per day, or $61 per cow for a pasture season of 161 days. With 3 acres of pasture per cow this would be a production of $20 an acre of pasture.

To pay for an application of any material costing $5 an acre in one year would require an increase in gross returns of more than 25% of the normal production under present conditions. However, the benefit derived from such improvement practices are not realized the first year but may continue throughout several years. The facts seem to be that the benefits are so protracted and additional pasture can be rented or pasture land purchased so cheaply that, where extra pasture is needed, this procedure is followed rather than money or time spent on the home pasture. In spite of this, the cheapness and high quality of pastures as a feed and the high freight rate and handling charges on concentrated feed stuffs purchased, so necessary to supplement poor pasturage, justify paying more attention to improving the plant food supply and the kind of grasses on pastures in the northeastern dairy belt.

## SUMMARY

The writer's belief concerning pasture improvement may be summarized thus:

1. Cleaning up the pasture is the first big job on the majority of farms.
2. Apply some manure on pastures where the hauling is reasonable and the pasture not too rough.
3. Improve with lime and superphosphate.

For the majority of pastures the first two recommendations are the horses and number three the cart. Let us not get the cart before the horses.

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## DISCUSSION

A question might be raised on the costs of maintaining pasture whether or not the figures presented are comparable. As given, the costs ranged from $1.45 to $16.78 per acre and the period covered from 1915 to 1927. However, more investigations would probably show considerable range in costs even in the same state.

Even though the value of the milk produced in the winter did not pay for the feed used, investigations in both New York and Iowa show that those farmers having the higher percentage of cows freshening in the fall and thereby running a winter dairy made the larger labor incomes. So regardless of the apparent lack of returns for winter milk, the farmers who produce it are the ones who make the greater net returns for the year. After all, the farmer is more interested in his total returns for the year than in the cost or the difference between the cost and the returns from any one enterprise of the business.

Whether or not a farmer should buy an adjoining abandoned farm is an individual problem and no general recommendation can be made. There are so many questions regarding it that a discussion is omitted here. It is also an individual problem just how much time a farmer can profitably spend on pasture improvement. Is there manure enough on the majority of farms to cover both pasture and crop land sufficiently? It is doubtful if diminishing returns have been reached in applying manure to crop land so that there is plenty left for pasture application. There is also some question whether or not cows will eat the grass the first season after manure has been applied.

At present hay is cheap in most places in New England and New York. The index number for hay in the latter state was 69 for the month of October, 1928. Some of this surplus hay land might well be put into pasture as is already being done in some sections in Massachusetts.

It is difficult to measure the value of manure per ton applied to different crops. Previous treatment of the soil may be an influential factor to be considered —ROLLIN H. BARRETT, *Massachusetts Agricultural College.*

# 3. PRACTICES AND CONDITIONS DETERMINING THE MOST PRODUCTIVE PERMANENT PASTURES IN NEW JERSEY[1]

HOWARD B. SPRAGUE[2]

According to the 1925 census, pasture land of all classes occupied an area equivalent to 30% of all crop land in New Jersey. In spite of this fact, the importance of pastures has been regularly overlooked. Very little information has been available regarding the practices and conditions associated with the production of large yields of feed per acre. Pasture experiments are notoriously expensive and this accounts for a part of the lack of experimental data. Because of the expense involved, care must be exercised to apply the funds available in such a manner that a maximum of results may be obtained.

Accordingly, the first step in pasture improvement in New Jersey has taken the form of a survey of conditions in representative areas of the state to determine the conditions and practices as they now exist and the phases of the problem which are of greatest importance. The survey was begun in the spring of 1926 and pastures were visited during April, May, and June. The field work was continued in the spring of 1927, and completed early in July of that year. A detailed report of the work has been published as circular 141 of the New Jersey State Dept. of Agriculture. H. W. Reuszer of the New Jersey Agricultural Experiment Station collected all of the records reported from this survey.

The information obtained was of two general types, *viz.*, (1) that obtained from the pasture directly, such as the area of the pasture, its topography, drainage, soil type, and the relative abundance of the various classes of vegetation occupying the soil; and (2) that obtained from the operator of the pasture, such as the details of management, including the number of stock grazed, the amount of additional feed supplied, and the milk produced by cows on pasture. Information of the latter type was obtained for the preceding year, but since the average condition of pastures was identical for the two years for which data were collected, they may be compared directly.

A total of 264 pastures was included in the survey, covering 4,710 acres. The pastures were located on 37 different soil types in the following five soil provinces: Glacial, Glacial Lake and River Terrace, Piedmont, Coastal Plain, and River Flood Plains. The pasture records were thrown into various groups for study, making the groups as large as possible so that the plus and minus errors would largely offset one another. The pastures chosen for the survey were those permanently in grass and grazed primarily by dairy cows. Many of the pastures were reported as having been in grass for many years, but those for which estimates were available had an average age of 18 years.

The vegetation occupying these pastures varied with the region, but in the northern half of the state over 13% of the total area of

[1]Paper read as part of the symposium on "Pasture Management Research" presented at the joint session of the New England Section of the Society and Section O of the A. A. A. S. held in New York City, December 28, 1928. Journal Series Paper of the N. J. Agr. Exp. Sta., Dept. of Agronomy.

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pastures was occupied by forests and scattering trees. Inedible shrubs, rushes, and sedges occupied an additional 10%, and weeds 25%, leaving the average area of the pasture occupied by forage plants as 52%. In the southern half of the state, occupied principally by the Coastal Plain soils, forests and scattering trees occupied about 2.0% of the total area, inedible shrubs, rushes, and sedges 10.5%, and weeds 15%, leaving 72.5% of the area occupied by forage plants.

Kentucky bluegrass was by far the most important forage plant on the surveyed pastures, making up 37.2% of all forage plants. Red top ranked second in importance with a value of 19.2%, followed by white clover with 7.8%; timothy, 6.8%; poverty grass, 5.7%; sweet vernal grass, 4.6%; the bent grasses, 3.0%; Canada bluegrass, 2.8%; and orchard grass, 2.0%.

The relative abundance of the various forage plants and of the more important weeds were recorded under varying conditions of drainage, soil texture, and soil type and have been included in the published report. It is noteworthy that forage plants were generally more abundant on fine-textured than on coarse-textured soils and this was particularly true of Kentucky bluegrass.

The carrying capacity of pastures was calculated in terms of feed units yielded per acre, using acceptable standards for converting the number of animal units grazed and the milk produced to this common basis. Using the feed units produced per acre as the measure, the Coastal Plain soils supported the best pastures, but Glacial Lake and River Terrace soils supported pastures which were nearly as valuable. Pastures on Glacial soils averaged the poorest of any soil province included in the survey.

It was found that the average amount of feed supplied by an acre for all pastures of the state for the years of the survey was equivalent to 2,130 pounds of alfalfa hay. The condition of pastures noted for the years of record was much below the average, so that the long-time average yield of pastures is probably well over this figure. If we assume the very conservative value for New Jersey of $25 for a ton of alfalfa hay, these pastures have been yielding feed worth $26.62 per year, a figure far above the usual estimates given on value of pastures.

The various management practices studied from the records were (1) the effect of mowing, (2) periodic versus continuous grazing, (3) deferring grazing in the spring, and (4) the use of commercial fertilizers, lime, and manure. Mowing once or more during the grazing season was practiced on about one-third of the pastures. In North Jersey, it was accompanied by a moderate increase in the proportion of forage plants and a proportionate reduction in other types of vegetation. For the state as a whole, mowing increased the production of feed 12.5%.

The periodic grazing practiced was of several types, varying from random grazing to a well-regulated system, with nearly one-half of all pastures receiving treatment falling in this category. Periodic grazing as a whole was an undesirable practice. Shrubs, sedges, rushes, and weeds were more abundant and forage plants less abundant

on pastures grazed periodically than on those grazed continuously. Continuously grazed pastures yielded 42.7% more feed per acre for the entire season than those grazed periodically. This does not, of course, preclude the possibility that rotation grazing may be very profitable when properly conducted.

Deferred spring grazing was practiced on all but nine of the pastures surveyed. It was found that early grazing was superior to later grazing in reducing the relative proportions of sedges, rushes, shrubs, and weeds, and in increasing the relative proportions of forage plants, particularly Kentucky bluegrass and white clover. In South Jersey, pastures on which grazing began before May 2 produced more than twice as much feed per acre per year as those first grazed between the dates of May 2 and May 14.

Neither commercial fertilizers, lime, nor manure are in common use on pastures throughout the state. It is only in localized areas in South Jersey that these materials are frequently applied to pastures. On such pastures it was found that substantial but rather haphazard applications of these three classes of materials, alone or in combination, were very effective in reducing the abundance of undesirable vegetation and in increasing the abundance of forage plants. In general, treatments with these materials increased the average yield of feed 17%. The data obtained were too meagre to determine the relative values of either manure or lime alone, or the relative values of the different fertilizer materials.

When grouped according to yields of feed per acre, it was found that 48 pastures had produced over 2,000 feed units per acre. The average for this group of better pastures was 2,823 feed units per acre, as compared with 1,065, the average for the entire 264 pastures surveyed. These better pastures were distributed generally throughout the state, apparently without respect to region or soil province. Their superiority seems to have been due mainly to better management practices rather than to differences in topography, drainage, soil texture, etc.

The 48 better pastures had fewer weeds, shrubs, sedges, and rushes, and a much larger proportion of forage plants than the average of all pastures. Kentucky bluegrass and white clover were particularly abundant on the better pastures. A much larger number of animal units were grazed on the better pastures than the average for all pastures, and less additional feed was required by the animals present. Continuous and early grazing was more common than the average; likewise the use of commercial fertilizers, manure, and lime was more common on these better pastures than on pastures generally.

## DISCUSSION

Considering this paper from the viewpoint of an extension worker who has had several years' experience in New Jersey, there are several things which it seems to me need attention and consideration. The general conclusions were that there were productive pastures in all parts of the state, that these were less encumbered with trees, brush, rushes, etc., had a higher percentage of Kentucky bluegrass and white clover and less weeds.

It would seem that too much emphasis was put on cultural practices such as mowing, grazing, etc., and not enough on soil fertility. Pasture conditions in New Jersey are not range conditions. The figures submitted show marked

superiority attributed to early grazing and to continuous grazing. An important factor which is not considered is that the good pastures were *ready* for grazing early, while there was no incentive to turn on the poor ones, where the grass was largely red top, till much later. Again, the good pastures were usually those where farming was more highly developed, land values higher, and acreage more limited so that the farmer probably had only one pasture, tried to have it a good one, and attempted to utilize it fully. Consequently, such pastures were grazed continuously and little grass was unutilized. Where there were several pastures, making intermittent grazing possible, they were all apt to be rough, wet, or brushy, the acreage large, and no effort was made to improve the pasture. In good years much grass was wasted. Consequently, the intermittently grazed pastures rated low.

Regarding the improvement shown from mowing, here again the personal element is important but unconsidered. The better farmer, who usually has better pasture and utilizes it more efficiently, took the pains to mow, while those with a large acreage, probably rough, bushy, or wet, did not mow.

Mowing is also offered as the principal weed control measure. Little attention is called to the real reason for most weeds in pastures, namely, a soil too poor or sour for the grasses to compete with the weeds.

Liming and fertilization gave an average increase of only 17% in production, barely enough to pav for their cost. snvestigation would probably show that the fertility treatment in South Jersey was largely applied on pastures already fair to good through natural fertility or past treatment. In practice, the pasture which needs treatment most seldom gets it.

The Coastal Plain pastures rated highest and the Glacial pastures the lowest. These represent the highest and lowest development and land value, and the lowest and highest soil acidities. Many of the Coastal pastures were small and not so long ago were tilled fields which received abundant lime, fertilizer, and manure. The Glacial pastures are usually large and rough, and if they were ever cropped, they were cropped to exhaustion.

Utilization is the measure of production. If all were fully utilized, this would be fair, but it brings in another factor and probably explains the low rating given the splendid river bottom pastures of the Piedmont, where the farmer seldom has stock enough to utilize the grass.

While the paper represents a large amount of work in survey and compilation of figures, it seems to place emphasis on minor points.—J. B. R. DICKEY, *Pennsylvania State College.*

Further discussion and replies to Mr. Dickey's criticisms were not possible, but the author does not believe that Mr. Dickey's objections to the results reported are well founded. For a clearer understanding of the paper and discussion, the reader is referred to N. J. Dept. of Agr. Circ. 141, a copy of which may be obtained from the author.—H. B. SPRAGUE.

## 4. ECOLOGICAL FACTORS DETERMINING THE PASTURE FLORA IN THE NORTHEASTERN UNITED STATES[1]

H. P. COOPER, J. K. WILSON, AND J. H. BARRON[2]

Very few systematic ecological studies have been made of the pasture flora in the northeastern states. The works of Sampson (62)[3] and others apply largely to the regions having a relatively light rainfall. The publications of Carrier (10), Carrier and Oakley (9), Graber (26, 27), Hutcheson and Wolfe (35), Schuster (65), Skinner and Noll (69), White and Holben (84), White and Gardner (85), Wiggans (89), and Sprague and Reuszer (73) represent some of the work which has been done in this region. British workers have

[1]Paper read as part of the symposium on "Pasture Management Research" presented at the joint session of the New England Section of the Society and Section O of the A. A. A. S. held in New York City, December 28, 1928.

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[3]Reference by number is to "Literature Cited," p. 624.

given more consideration to the fundamental factors underlying good pasture management. A good review of their work is found in a book entitled "Grass Land, Its Management and Improvement" by Stapledon and Hanley (75). Sommerville (72), Elliott (18), Cruickshank (14), Godden (25), and Woodman, et al. (90) have also made recent valuable contributions to this subject.

Both climate and soil are important factors which influence the flora of pastures. Certain species of plants are very sensitive to climatic conditions. Red fescue (*Festuca rubra*) in New York is largely restricted to the Champlain Valley, dominating in some of the best pastures of that region. Warm dry conditions are detrimental to Rhode Island bent grass (*Agrostis tenius*). Some of the best pastures in New York are composed largely of this grass and white clover. The exacting climatic requirements of Rhode Island bent grass definitely limit its usefulness as a pasture plant to regions which are relatively moist and cool. Climatic variations within a distance of 10 to 20 miles are often sufficient to determine its success or failure in pastures.

The determinations of H-ion concentration of some 1,200 samples of air-dried soil from under pasture vegetation indicate that there is not a very close correlation between the pH values obtained from a water suspension of these soils and the type of plants growing on them. It has been pointed out by Cooper and Wilson (13) and by Pearsall (59) that the quantity and quality of the cations (bases) in the soil complex may be more important than the pH value of the soil in determining its adaptability for the growth of certain plants. Wherry (83) reports the divergent soil reaction preferences of related plants grown under diverse climatic and soil conditions. This divergent soil reaction preference is possibly related to the difference in the availability of the various nutrient ions under diverse climatic and soil conditions.

## RELATION OF CATIONIC EXCHANGE PROPERTIES OF SOILS TO PLANT GROWTH

Table 1 gives the standard electrode potentials of some common nutrient materials. The electromotive series of elements is based upon their electrical properties. It is one of the best groupings for giving a general idea of the properties of substances. Every form of energy may be considered as compounded of two factors, one the capacity factor and the other the intensity factor. With electrical energy the quantity of electricity expressed in suitable terms, say coulombs, is the capacity factor, and the electrical pressure expressed in suitable units, say volts, is the intensity factor (51).

Since the standard electrode potentials are a relative measure of the intensity factor, they should be of special interest to the biologist. Those interested in absorption and nutrition studies should be particularly concerned with the relative electrical pressures or the intensity factor, that is, the intensity with which electrical energy tends to become active. The chemical affinity between reacting substances may be roughly expressed in terms of differences in electrical potential. Since so much emphasis has been placed on the

TABLE 1.—*The rate of absorption of substances by organisms seems to be correlated with the oxidation reduction potentials of the various materials.*

Approximate standard electrode potentials in volts; molar H electrode = 0

| | Charge | E. M. F. in volts |
|---|---|---|
| A. Cations (+) ion | | |
| Potassium | $K^+$ | —2.93 |
| Sodium | $Na^+$ | —2.70 |
| Calcium | $Ca^{++}$ | —2.50 |
| Magnesium | $Mg^{++}$ | —1.50 |
| Aluminum | $Al^{+++}$ | —1.30 |
| Manganese | $Mn^{++}$ | —1.10 |
| Zinc | $Zn^{++}$ | —0.76 |
| Ammonia | $NH_4^+$ | —0.55 |
| Amines, etc | —— | —— |
| Iron | $Fe^{++}$ | —0.43 |
| Cobalt | $Co^{++}$ | —0.29 |
| Nickel | $Ni^{++}$ | —0.22 |
| Tin | $Sn^{++}$ | —0.13 |
| Iron | $Fe^{+++}$ | —0.04 |
| HYDROGEN | $H^+$ | 0.00 |
| Antimony | $Sb^{+++}$ | +0.10 |
| Copper ($Cu^+$) | $Cu^{++}$ | +0.17 |
| Arsenic | $As^{+++}$ | +0.29 |
| Copper | $Cu^{++}$ | +0.34 |
| Copper | $Cu^+$ | +0.52 |
| Mercury | $Hg^{++}$ | +0.80 |
| Silver | $Ag^+$ | +0.80 |
| Platinum | $Pt^{++}$ | +0.86 |
| Gold | $Au^+$ | +1.50 |
| B. Anions (−) ion | | |
| Ferrocyanide $Fe(CN)_6^{----}$ | $Fe(CN)_6^{---}$ | +0.40 |
| Hydroxyl | $OH^-$ | +0.41 |
| Silicon | $SiO_3^{--}$ | —— |
| Carbon | $CO_3^{--}$ | —— |
| Boron | $BO_3$ | —— |
| Nitrogen | —— | —— |
| Phosphorus | —— | —— |
| Sulfur $S^{--}$ | $S^0$ | —0.55 |
| Iodine | $I^-$ | +0.55 |
| Nitric oxide | —— | +0.95 |
| Oxalate | $C_2O_4^{--}$ | +0.95 |
| Bromine | $Br^-$ | +1.08 |
| Hydrazoic acid ($HN_3$) | $N_3^-$ | +1.29* |
| Chlorine | $Cl^-$ | +1.35 |
| Acetic acid | $CH_3COO^-$ | +1.57* |
| Nitrate | $NO_3^-$ | +1.69* |
| Phosphate | $H_2PO_4^-$ | +1.70* |
| Sulfate | $SO_4^{--}$ | +1.90 |
| Oxygen | $O^{--}$ | +1.90 |
| Fluorine | $F^-$ | +1.96 |

*Discharge potential of acid.

H ion in biological work, it is interesting to note its relative position in the potential series.

A high H-ion concentration cannot exist in the presence of available material which produces strong cations unless there are also strong anions present in the system. Since a low H-ion concentration may be due to the presence of strong cations or to the absence of strong anions, it is easy to see why there is not always a close correlation between the growth of organisms and the H ion concentration of the nutrient medium. It is easy to see why the quantity and quality

of the cations and anions in soil complexes may be more important than its pH value in determining the suitability of a soil for the growth of certain plants.

In a previous paper (13) it was suggested that a given H-ion or OH-ion concentration resulting from the presence of various acidic and basic materials may produce very different nutritional complexes. We can only evaluate the importance of the H ion in a nutrient system in terms of its relative strength with reference to other nutrient ions. The H ion is considered an acid because it holds its charge less tenaciously than do the other metals which are above it in the electromotive series. Since the H ion is one of the weakest of the active cations, its combination with anions produce numerous acids. The strength of an acid so produced is determined by the strength of the anion. The weak anions, such as OH, $SiO_3$, $CO_3$, and I, when combined with the H ion, form weak acids, while the strong anions, such as F, $SO_4$, $NO_3$, and Cl, produce strong acids.

Snyder (71) has pointed out the significant fact that the pH value is a measure of the intensity factor of acidity and not the quantity of acids or acid substances present. He also presents an excellent discussion of the determination of the H-ion concentration of soils. The H potential as expressed by the pH value of the soil complex or any nutrient medium can be interpreted intelligently only in relation to the relative strength of the H ion with respect to the strength of other ions in nutritional complexes. Until the significance of the relative position of H in the electromotive series is more generally appreciated there is apt to be much useless and expensive, empirical experimentation in the field of nutrition and related subjects. Those desiring further information concerning the significance of the electromotive series will find it discussed by Mellor (51) and in standard books on physical chemistry and physics.

It is generally believed that there is a relation between the amount of exchangeable nutrient cations which are relatively high in the potential series and the productivity of the soil. Data reported by Mattson (45) may be interpreted to show that there is a close correlation between the standard electrode potential of materials and the removal of cations by electrodialysis of a soil colloid. The quantitative order in which the different ions appeared in the cathode chamber in three successive fractional electrodialyses are about as follows: Ca, K, and Na; Mg; and Al, Mn, and Fe. Since most of the Ca, K, and Na were removed in the first fraction, these data do not show the actual qualitative order of removal of the ions. It is probable that the order of removal of cations by electrodialysis is related to the electromotive tension series, also to the solubilities and the ionization of their hydroxides. The order of solubilities of the hydroxides in water is about as follows: Na, K, $NH_4$, Ca, and Mg. The hydroxides of Al, Mn, and Fe are only slightly soluble or are insoluble in water; but they are more soluble in an acid medium. The specific conductance of ions may be an important factor in determining the order of appearance of unadsorbed cations in the cathode chamber in electrodialysis of soil colloids.

Menchikowsky and Ravikovitch (50) have concluded that the distribution of cations in soil extracts corresponds to the partial decomposition pressures of the compounds formed by the adsorbed cations with the alumino-silicate group. This might be expected, since the adsorption of ions is related to the potential series which is a relative measure of the electrolytic solution pressures of the elements.

TABLE 2.—*Average amounts of exchangeable cations from 12 soil samples as determined by means of extraction with normal $NH_4Cl$ and by electrodialysis.*

| Cation | Milligram equivalents removed per 100 grams air-dry soil | | |
|---|---|---|---|
| | $NH_4Cl$ extraction amount | Electrodialysis Amount | Electrodialysis Percentage of $NH_4Cl$ extraction |
| Ca | 7.54 | 6.87 | 91.0 |
| Mg | 2.84 | 1.04 | 36.5 |
| K | 0.89 | 0.68 | 77.1 |
| Total | 11.27 | 8.59 | 76.2 |

Wilson (87) found, as shown in Table 2, that larger quantities of exchangeable cations were extracted from soil with normal $NH_4Cl$ than by electrodialysis. An average of the values for 12 soils shows electrodialysis to yield only 91.0%, 36.5%, and 77.1% as much Ca, Mg, and K, respectively, as did extraction with normal $NH_4Cl$. Considerably more magnesium was removed by extraction with normal $NH_4Cl$ than by electrodialysis. The relatively small proportion of Mg removed by electrodialysis is probably related to its relatively low electrolytic solution pressure and to the relatively low solubility of $Mg(OH)_2$ in water. Magnesium is very much more soluble in the presence of ammonium salts than in water.

Data presented by MacIntire (47) on the reciprocal repression of calcic and magnesic materials added to soils on the solubility of native soil materials are of special interest. The data of Mattson and of Wilson indicate that the metals with relatively low standard electrode potentials are not readily removed by electrodialysis from the soil colloidal complex. There is some difference of opinion concerning the exchange ability of trivalent materials with relatively low electrolytic solution pressures, such as Al and Fe. It is not probable that large amounts of the metals with relatively low standard electrode potentials, which form hydroxides insoluble in water, exist in exchangeable form in the soil colloidal complex. Metals with relatively low electrolytic solution pressures become readily reactive only in the absence of strong cations, or in the presence of strong or high potential anions. It is well known that on acid soils certain plants absorb relatively large amounts of materials which have comparatively low standard electrode potentials.

The $NH_4$ ion is included in the cation series in Table 1. It should not be overlooked, however, that $NH_4$ is a compound ion with a valence shell electron configuration similar to that of the alkali metal ions. It has many properties of the ions in the alkali family of elements, but its ionization constant is relatively low. With a suitable current Bradfield (5) found it possible to remove $NH_4$ quantitatively from a soil saturated with $NH_4$ ions. With too strong current some of the volatile $NH_3$ which is discharged at the cathode

may be lost along with the H gas, since the $NH_4$ ion has a relatively low discharge potential. In this connection it is interesting to note that there is a large decrease of $NH_3$ in certain acid soils on drying. Some of this loss may be due to volatilization as well as oxidation, since $NH_3$ is a volatile hydride.

Investigations dealing with cation exchange as reported by Bradfield (6), Burgess and Breazeale (8), Gedroiz (21), Humfeld (34), Joffe and McLean (37, 38, 39), Kelley (42), Kelley and Brown (40, 41), Kerr (43), Magistad (44), MacIntire, et al. (46), Merkle (52), Oden (53), Page (55, 56), Parker (58), Parker and Pate (57), Sewell and Perkins (66), Spurway (74), and others are of interest in this connection.

## RELATION OF ELECTROMOTIVE SERIES TO ABSORPTION OF IONS BY ORGANISMS

A number of investigators have reported data which illustrate the fact that there is a general correlation between the initial or qualitative order of absorption of nutrient ions by organisms and the electromotive series. It has been noted by Irving (36) and others that there is a correlation between the order and rate of absorption of ions by organisms and the Hofmeister series. The electrostatic effect as expressed by the potential series is undoubtedly one of the dominant factors in determining the Hofmeister series. However, under certain conditions such factors as concentration, solvation of ions, and H-ion concentration may be significant in determining the order of ions in the so-called Hofmeister series.

The correlation between the potential series and the order of ion absorption by organisms would not be expected to be as close as the relation between the removal of ions in electrodialysis of colloidal material and the potential series; because such factors as ion activity, solvation of ions, mobilities of ions, photosensitivity of compounds, and character of membrane may also influence absorption of ions. The selective absorption of certain materials with relatively high standard electrode potentials suggests that, within certain limits, organisms may absorb positive or negative charges of electricity rather than any specific ions. If such is the case, it may partially account for the selective absorption of the stronger ions, such as K, by organisms.

Stiles (76) gives a good review of the theories of permeability. A recent book by Buchanan and Fulmer (7) contains an excellent discussion of the chemistry underlying many fundamental physiological processes. There are considerable data which definitely suggest that certain organisms and perhaps certain tissues selectively absorb isosteric ions.

Elements tend to form atomic ions which have the outer shell electron configuration of either the nearest noble gas in the periodic system of the elements, or an 18-shell group. The following are examples of isosteric ions:

(a) $O^{--}$, $F^-$, *Ne*, $Na^+$, $Mg^{++}$, $Al^{+++}$

(b) $S^{--}$, $Cl^-$, *A*, $K^+$, $Ca^{++}$, $Mn^{++}$, $Fe^{+++}$

The selective absorption of groups of ions may be related to their size or dimensions. There are a number of factors affecting the absorp-

tion of ions, therefore, extreme care is necessary in the application of the potential series to biological problems. Its intelligent use requires an understanding of the fundamental relationships involved in the development of such a series. This general topic will be more fully discussed in a separate paper.

It is probable that nutrient anions, particularly nitrates and phosphates are just as important as are cations in nutrition. Since N and P are in the same family of elements, they are qualitatively alike, therefore, they should have similar effects in the nutrition of organisms. A liberal amount of one of these nutrients may enable an organism to function normally with a minimum quantity of the other. The ease with which pentavalent N and P undergo a change of valence when exposed to the radiant energy of sunlight probably facilitates the shifting of valence bonds, which accompanies photosynthesis in plants. The $NO_3$ ion is one of the relatively strong anions which is sensitive to the radiant energy of visible light. This sensitivity may be one of the reasons why it is so effective in certain nutritional complexes which contain large amounts of the relatively strong ions.

The sulfides and halides of the metals, which have relatively low standard electrode potentials, are also markedly sensitive to radiation, but the alkali halides are relatively inactive. With the exception of F all the halogens are sensitive to visible light. Chlorine is most sensitive to blue, violet, and ultra-violet radiation. Bromine is more sensitive to the longer wave lengths than is Cl, while I absorbs still more of the longer wave lengths. The marked contrast in the physiological effects of F and I may be related to their sensitivity to radiation. The differential optimum nutritional requirement of various species of plants may be related to their capacity to absorb different quanta of radiant energy.

The tolerance of certain plants to $SiO_3$, $C_2O_4$ (15), $CO_3$, and other relatively weak anions may be an important factor in determining the dominant type of native vegetation. The relatively weak ions form compounds which are usually more sensitive to light or electrical radiation than are the compounds formed from strong ions. Further information concerning this topic can be found in the publications of Hughes (32, 33), Bazzoni (4), and Taylor (79). The photosensitive compounds formed from weak ions undoubtedly perform an important rôle in the nutrition of both plants and animals. A well-balanced nutrient complex is necessary for optimum growth. It is not possible, therefore, to correlate the growth of organisms with the concentration of any single ion. Skeen (68) found in sand cultures with balanced nutrient solutions that the growth of *Agrostis alba* var. *stolonifera* is practically independent of H-ion concentration within the limits of pH 3.7 to 6.0. The work of Aarnio (1) on the influence of adsorbed ions on soil reaction is of special interest in this connection.

The pH values of some pasture soils before and after air drying definitely suggest that a closer correlation exists between plant growth and the pH values of moist soils than between plant growth and the pH values of dried soils, particularly on certain acid soils. It is probable that the volatile nitrogenous bases, including $NH_3$, are often important factors in the base exchange complex of certain acid soils, as indicated by data presented by Merkle (52), and may greatly

influence the type of vegetation suitable to a given soil. The acidic hydrides may also be important factors in certain situations.

Those plants which may utilize cationic ($NH_3$, etc.) nitrogen to advantage often dominate on certain of the more acid soils. Those which seem to prefer anionic ($NO_3$) nitrogen, or a nutritional complex favorable for the production of $NO_3$, are apt to dominate on soils which are well supplied with Ca or other materials which are high in the electro-motive series.

More than 50 years ago Hilgard (30) attempted to correlate the natural vegetation on soils with their Ca content. In many cases it was found that there was little or no relation between the percentage of Ca in the soil and the native vegetation growing on the soil. Little progress could be made with such investigations without the modern conception of the nature and function of the colloidal material in the soil. The available data definitely suggest that there is a closer correlation between the growth of plants and the ratio of colloidal material to the available reactive cationic materials, which have relatively high standard electrode potentials, than there is between the actual percentage of basic material in a soil and plant growth. McCool (48) has discussed the relation of colloids to soil productivity. In saline soils common in dry climates the Na ions and the K ions may predominate in the colloidal complex; but in most cool humid regions the ratio of Ca to colloidal content, or the ratio of Ca plus Mg to colloidal content, may correlate more closely with the native vegetation than the actual percentage of Ca or Mg in the soil. The electrolytic solution pressures of K and Na are too high for these ions to be adsorbed in large amounts by the soil colloidal complex in humid climates. Calcium has a lower electrolytic solution pressure than the alkali metals, therefore, the Ca ion may be adsorbed in large amounts by the soil colloidal complex in humid climates and is often the dominant exchangeable cation in some of the more productive soils.

## RELATION BETWEEN SOIL CHARACTERISTICS AND NATIVE VEGETATION

Natural vegetation is an expression of environment. It is an integration of all climatic and soil factors, and it often provides a better basis for a classification of the environment than any other factor or set of factors. When carefully analyzed and classified the natural vegetation of a country, according to Shantz and Zon (67), may serve a concrete and practical purpose. The suitability of virgin lands for various crops is often clearly indicated by natural vegetation.

The various pasture plants tolerate different nutritional complexes in soils. Kentucky bluegrass is one of the most widely distributed dominant pasture grasses in the northeastern states. It is soft and palatable and grows best on soils which are well supplied with relatively soft elements such as K, Ca, P, and other elements with relatively high oxidation reduction potentials. The harder and less palatable plants such as Rhode Island bent grass, sweet vernal grass, poverty grass, sedges, ferns, and mosses are likely to dominate on the more acid soils. These harder plants can probably utilize the harder elements, such as Mg, Al, Mn, Fe, Si, and other materials,

which have relatively low oxidation reduction potentials. Hall and Morison (28) and Schollenberger (63) have reported data which indicate that Si may be utilized as a nutrient by certain plants.

Table 3 gives the relative hardness of the various elements. Silicon is one of the hardest elements and the presence of large amounts of it in a plant may partially account for the lack of palatability of certain plants. Other elements, such as Mn, Al, Fe, and Mg, are relatively hard elements and the presence of large amounts of these in plants may influence their palatability and nutritional value.

TABLE 3.—*Relative hardness of the elements.**
After Olsen (54).

| | | | |
|---|---|---|---|
| C (diamond) | 10.0 | Au | 2.5 |
| B | 9.5 | Te | 2.3 |
| Cr | 9.0 | Ce | 2.0 |
| Os | 7.0 | S | 2.0 |
| Si | 7.0 | Se | 2.0 |
| Ir | 6.5 | Mg | 2.0 |
| Ru | 6.5 | Sn | 1.8 |
| Mn | 5.0 | Sr | 1.8 |
| Pd | 4.8 | Ca | 1.5 |
| Fe | 4.5 | Ga | 1.5 |
| Pt | 4.3 | Pb | 1.5 |
| As | 3.5 | In | 1.2 |
| Cu | 3.0 | Li | 0.6 |
| Sb | 3.0 | P | 0.5 |
| Al | 2.9 | K | 0.5 |
| Ag | 2.7 | Na | 0.4 |
| Bi | 2.5 | Rb | 0.3 |
| Zn | 2.5 | Cs | 0.2 |

*Smithsonian Tables, 1914, Vol. 63.

TABLE 4.—*Analysis of pasture plants in Great Britain, average results for six pairs of samples.*

| Material | Eaten (A) % | Not eaten (B) % | B expressed as a percentage of A |
|---|---|---|---|
| Lime (CaO) | 0.464 | 0.264 | 56.9 |
| Phosphorus ($P_2O_5$) | 0.516 | 0.325 | 63.0 |
| Sodium ($Na_2O$) | 0.151 | 0.160 | 106.0 |
| Potash ($K_2O$) | 2.394 | 1.533 | 64.0 |
| Chlorine (Cl) | 0.561 | 0.291 | 51.9 |
| Nitrogen (N) | 2.211 | 1.831 | 82.8 |
| Total ash | 6.184 | 3.433 | 55.5 |
| Silica-free ash | 4.663 | 2.733 | 58.6 |
| Fiber | 24.6 | 29.6 | 120.3 |
| Calories per 100 grams | 277.0 | 268.0 | 96.7 |

TABLE 5.—*Comparison of hill and lowland pastures from the same locality.*

| Material | Scotland | | Montgomeryshire | | Cardiganshire | |
|---|---|---|---|---|---|---|
| | Hill % | Lowland % | Hill % | Lowland % | Hill % | Lowland % |
| Lime (CaO) | 0.152 | 0.821 | 0.788 | 0.947 | 0.352 | 1.080 |
| Phosphorus ($P_2O_5$) | 0.420 | 0.875 | 0.429 | 0.869 | 0.652 | 0.788 |
| Sodium ($Na_2O$) | 0.115 | 0.393 | trace | 0.037 | 0.051 | 0.416 |
| Potash ($K_2O$) | 2.226 | 3.017 | 3.062 | 4.360 | 3.423 | 2.988 |
| Chlorine (Cl) | 0.644 | 0.747 | 1.706 | 1.078 | 1.086 | 1.132 |
| Nitrogen (N) | 2.269 | 3.301 | 2.189 | 4.005 | 2.624 | 3.374 |
| Total ash | 4.267 | 8.606 | 7.683 | 10.551 | 6.756 | 10.308 |
| Silica-free ash | 4.020 | 6.884 | 5.490 | 8.472 | 5.796 | 7.288 |
| Fiber | 25.50 | 18.30 | 24.09 | 17.22 | 24.71 | 16.13 |
| Calories per 100 grams | 282.0 | 295.0 | 273.0 | 289.0 | 274.0 | 294.0 |

The data reported by Godden (25), found in Tables 4 and 5, show that the more palatable, or the eaten, plants are usually much higher in the desirable mineral nutrients, such as Ca, P, and K, than the non-eaten plants with the exception of Na. The non-eaten plants relatively less of the nutrient elements with relatively high dard electrode potentials. The non-eaten plants seem to be olerant of the harder elements with relatively low standard electrode potentials. The above tables clearly show that there is a great difference in the amount of desirable mineral nutrient materials in pasture plants grown under various conditions. Such desirable mineral nutrients as Ca, P, and K, are much lower in plants grown on poor hill pastures than in those grown on the better valley pastures.

The lack of adequate minerals in forage plants is undoubtedly an important factor in the nutrition of dairy animals in the northeastern states, especially on the poorer acid soils where Rhode Island bent grass, sweet vernal grass, and poverty grass are common pasture plants. Kentucky bluegrass and white clover have a high fertility requirement and do not grow well on the poorer soils. Hence, Kentucky bluegrass and white clover are desirable pasture plants, since they contain relatively large amounts of the desirable mineral nutrients.

## CLIMATIC AND SOIL CONDITIONS FAVORING THE DOMINANCE OF VARIOUS PASTURE PLANTS

**White clover** (*Trifolium repens*) is one of the widely distributed pasture plants in the northeastern states. It is most abundant in closely grazed pastures on relatively fertile soils. But it is tolerant of the nutrient elements relatively low in the potential series.

**Kentucky bluegrass** (*Poa pratensis*) is one of the best pasture plants. It is the most common pasture grass on the relatively fertile soils well supplied with Ca, P, and other nutrient materials with relatively high standard electrode potentials. It is common in many night pastures and in most of the better valley pastures in every section of the region. It grows very little, however, during the hotter and dryer portions of the season.

**Canada bluegrass** (*Poa compressa*) has a similar climatic and soil requirement to that of Kentucky bluegrass. It is relatively harder and may be less palatable than Kentucky bluegrass. Since it grows relatively well on the less productive and the poorly drained soils, it may be able to utilize the relatively hard nutrient elements or those with relatively low standard electrode potentials.

**Red fescue** (*Festuca rubra*) is confined largely to the Champlain Valley region. It seems to do well on sandy soils as well as on the heavier, more productive soils. It grows well only during the early part of the season. It is a hard grass and not very palatable.

**Rhode Island bent grass** (*Agrostis tenuis*) is sensitive to warm dry conditions. The exacting climatic requirements of this plant definitely limit its usefulness as a pasture plant to regions which are relatively cool and moist. Since this plant grows well on relatively poor soils, it is a very important pasture plant in the hill pastures of

the eastern and northern plateau regions of New York where the growing season rainfall is sufficient. It is tolerant of the nutrient elements with relatively low standard electrode potentials. It has been observed that this plant often contains large amounts of S when it is grown on some of the depleted soil derived from ign rock which are found in the Adirondack region. It is very prob that Si may partially substitute for phosphorus in the nutritiona requirement of this plant.

**Creeping bent grass** grows well on wet soils and should be an important plant in all swampy or wet pastures.

**Sweet vernal grass** (*Anthoxanthum odoratum*) is very common in the poor hill pastures of southeastern New York. It is commonly associated with Rhode Island bent grass in this region. It is not of much value as a pasture plant.

**Poverty grass** (*Danthonia spicata*) grows well on poor soils and is often the most common plant in run-out or depleted hill pastures in every section of New York. It is a very poor forage plant.

**Trees and other weedy plants,** such as pine, cedar, spruce, gray birch, aspens, mosses, cinquefoil, paintbrush, and hardhack, are common on run-out or depleted pastures in need of fertilization.

## SUCCESSION OF PLANT ASSOCIATIONS ON PASTURE LAND

When timber is first removed from the land conditions are favorable enough for the growth of Kentucky bluegrass and white clover on practically every well-drained soil type in the northeastern states. There is apt to be sufficient nutrient material in the organic residues of the soil for the growth of crops requiring a high fertility level. The duration of a good bluegrass sod in pastures is greatly influenced by the condition of the soil.

Data reported by Glinka (24) from podsolic soils show that the upper soil horizons may contain more of the materials such as potash and calcium, with relatively high standard electrode potentials, than the subsurface horizons.

The data in Table 6 were taken from the soil survey reports of several counties in southern Illinois. Some of these soils contain distinct clay pans, which are often characteristic of fine-textured soils low in Ca. Some of the soil samples were from the red top (*Agrostis palustris*) region of Illinois. The data clearly indicate that there is approximately 16% more Ca in the surface than the subsurface. This accumulation of Ca in the surface soil is probably partially due to the removal of Ca by plants from the subsurface and its accumulation in the surface from organic residues. These data suggest that the Ca in certain soils may be relatively inactive or immobile.

Data reported by Wilson (88) suggest that the downward movement of Ca in fine-textured soils low in Ca is very slow.

Since there are large areas of swamp and peat land pastures in the northeastern United States, the data contained in Table 7, calculated from analyses of European peat soils which were compiled by Dachnowski (16), may be of interest. These data show a correlation of $-0.51 \pm .06$ between the width of the N:C ratio and the CaO content in 68 samples of peat materials.

The data in Table 8 were calculated from analyses of mineral and peat soils made in the United States. These data are similar to those of the European peat samples. The data from both these sources illustrate the fact that there is a relation between the CaO content and the width of the N:C ratio which may reflect the suitability of such soils for various plants.

TABLE 6.—*Showing the apparent accumulation in the surface or little downward movement of Ca in fine-textured soils low in total Ca. Clay, Harden, and Johnson Counties, Illinois.*

| Sample No. | (1) 0–6 2/3 inches | (2) 6 2/3–20 inches | (3) 20–40 inches | Difference D (1 and 2) | $D^2$ |
|---|---|---|---|---|---|
| 1 | 3,000 | 3,420 | 3,960 | —420 | 176,400 |
| 2 | 3,040 | 2,300 | —— | 740 | 547,600 |
| 3 | 3,370 | 2,345 | 3,266 | 1,025 | 1,050,625 |
| 4 | 3,420 | 3,810 | 6,610 | —390 | 152,100 |
| 5 | 3,980 | 3,825 | 6,527 | 155 | 24,025 |
| 6 | 4,010 | 3,275 | 3,620 | 735 | 540,225 |
| 7 | 4,020 | 2,540 | 6,240 | 1,480 | 2,190,400 |
| 8 | 4,060 | 4,060 | 3,640 | 0 | 0 |
| 9 | 4,320 | 3,880 | 5,540 | 440 | 193,600 |
| 10 | 4,390 | 4,030 | 4,110 | 360 | 129,600 |
| 11 | 4,620 | 3,920 | 4,440 | 700 | 490,000 |
| 12 | 4,620 | 3.460 | 4,560 | 1,160 | 1,345,600 |
| 13 | 4,900 | 3,940 | 3,680 | 960 | 921,600 |
| 14 | 6,040 | 4,650 | 6,700 | 1,390 | 1,932,100 |
| 15 | 6,270 | 5,760 | 5,760 | 510 | 260,100 |
| 16 | 6,920 | 3,940 | 3,590 | 2,980 | 8,880,400 |
| 17 | 7,720 | 6,960 | 8,920 | 760 | 577,600 |
| Total | 78,700 | 66,115 | 81,163 | 12,585 | 19,413,775 |
| Average | 4,629 | 3,889 | 5,073 | 740 | 1,141,987 |
| Per cent of surface | 100 | 84 | 109 | | |

$$\sigma^2 = 1,141,987 - (740)^2 = 594,387$$

$$\sigma = 771$$

$$Z = \frac{M}{\sigma} = \frac{740}{771} = 0.98 = \text{Odds } 1,637 \text{ to } 1$$

Waksman (82) has pointed out the significance of the microorganisms upon the N:C ratio in the soils and their relation to the availability of anionic N for higher plants. It is observed that there is a difference in the type of vegetation dominating on various types of peat. This suggests that there may be a great difference in the nutritional value of the pasture plants grown on various types of peat and marsh soils.

TABLE 7.—*Correlation of high CaO content with narrow N:C ratio and productivity in various European types of peat and muck.**

| Type of peat material | CaO: Number of samples | CaO: Average CaO % | N:C ratio†: Number of samples | N:C ratio†: Average | N:C ratio†: Range |
|---|---|---|---|---|---|
| Colloidal (muck) | 3 | 2.59 | 5 | 1:15 | 1:9 to 1:22 |
| Marsh-reed grasses | 6 | 2.67 | 10 | 1:19 | 1:13 to 1:32 |
| Marsh-sedges | 8 | 2.15 | 8 | 1:19 | 1:13 to 1:26 |
| Macerated | 4 | 0.86 | 7 | 1:25 | 1:9 to 1:48 |
| Swamp-elder type | 5 | 4.48 | 4 | 1:18 | 1:12 to 1:27 |
| Swamp-birch type | 5 | 0.49 | 5 | 1:29 | 1:21 to 1:39 |
| Bog moss | 11 | 0.43 | 14 | 1:52 | 1:31 to 1:73 |

*Samples taken from surface to 6 to 8 feet deep.

†These ratios are calculated on the basis of 50% of C in the organic matter.

Hall and Russell (29) found that there is a wide variation in the quality of pasture plants on the marsh lands of southeastern England. One of the most striking characteristics of the soils in the fattening pastures was the high rate at which nitrates were produced. They also contained relatively large amounts of total phosphoric acid.

TABLE 8.—*Showing that high-lime peat and muck have a narrow N:C ratio and are usually productive.**

| Type of soil | Number of samples | CaO Average % | CaO Range | N:C ratio* Average | N:C ratio* Range |
|---|---|---|---|---|---|
| Mineral soils, Ill. | 60 | 0.655 | 0.266 to 4.571 | 1:12 | 1:8 to 1:16 |
| High-lime peat, Ill. | 16 | 3.21 | 1.27 to 16.4 | 1:12 | 1:8 to 1:13 |
| High-lime peat, Minn. | 4 | 2.36 | 1.01 to 2.59 | 1:13 | 1:13 to 1:16 |
| Low-lime peats, Minn. | 2 | 0.35 | 0.31 to 0.40 | 1:27 | 1:21 to 1:33 |
| Sedimentary peat muck. | 3 | —— | —— | 1:11 | 1:9 to 1:15 |
| Woody peat | 4 | —— | —— | 1:20 | 1:17 to 1:25 |
| Fibrous peat | 13 | —— | —— | 1:28 | 1:12 to 1:90 |

*These ratios are calculated on the basis of 50% of C in the organic matter. The data used in making these calculations were taken from Ill. Agr. Exp. Sta. Soil Rpts. Nos. 20, 22, 23, 26, 28; Minn. Agr. Exp. Sta. Bul. 188; and a paper by Dachnowski (17).

Marsh grasses, sedges, and alders often dominate on high-lime peat soils, while such plants as birch, pine, tamarack, spruce, and bog moss are apt to dominate on low-lime peat soils. An inspection of the data giving the lime content and the average and the minimum width of the N:C ratio shows that highly productive peat soils may be found in the grass, sedge, and alder types. Those types with a N:C ratio narrower than 1:10, when cultivated, may develop toxic amounts of nitrates if they are not carefully managed. The wide N:C ratios found in birch and bog moss types of peat are correlated with low Ca content. In the natural state the conditions in such soils (12, 19) are not favorable for the production of nitrates, but are favorable for the dominance of plants which can probably utilize cationic ($NH_3$, etc.) N and other cations with relatively low standard electrode potentials.

The removal of the cationic N from the plant residues by the growing vegetation would not leave sufficient available N for the biological oxidation of the residues. This removal of cationic N would result in the accumulation in and on the soil of organic matter with a relatively wide N:C ratio. There is apt to be a heavy accumulation of organic matter under forest vegetation which apparently utilizes to good advantage cationic N. This idea is best illustrated by the so-called "internal ionized salt" discussed by Williams (86). The base-forming properties and their ability to form salts with acids is one of the important characteristics of amines. Aminoacetic acid ($NH_2$—$CH_2$—COOH) is one of the simplest aminoacids.

It is suggested that a so-called internal ionized salt may be illustrated as follows:

$$NH_3^+—CH_2—COO^-$$

If such a material were hydrated, it is possible that cation exchange may take place and H take the place of $NH_2$ or $NH_3$ group, leaving an organic residue relatively high in H and C. Organic mat-

ter does have cation exchange capacity, but it is possible that it may be due to adsorption phenomena. Such an exchange and the accumulation of organic acid radicals may greatly influence the podsolization of soils under native vegetation which may use mostly ammonic N.

Virtanen (81) suggests that various plants differ in their abilities to utilize efficiently $NH_2$-acids as a source of N. Rayner (60) has summarized some of the available data on the utilization of different forms of N by various types of native vegetation. Glinka (24) has presented a large amount of data showing the relation between types of vegetation and the chemical and physical properties of soils under each. One would expect the soil conditions under the various types of native timber vegetation to be reflected in the associations of pasture plants after the timber is removed. The succession of the various pasture plant associations following such vegetation as pine spruce, hemlock, birch, and soft maple would be expected to follow each other in rapid succession; while following such native vegetations as hickory, ash, beech, elm, hard maple, and other types of vegetation requiring a relatively high-fertility level the pastures would be expected to remain in the Kentucky bluegrass and white clover association for a much longer period. However, such soils may be finally depleted sufficiently for the dominance of the plant associations tolerant of a low-fertility level.

TABLE 9.—*Succession of plant associations on pasture lands.*

| Associations | Warm to cool relatively dry regions | Cool moist regions | Cold moist regions |
|---|---|---|---|
| 1 | Kentucky bluegrass<br>Canadian bluegrass<br>White clover | Kentucky bluegrass<br>Canadian bluegrass<br>White clover | Kentucky bluegrass<br>Canadian bluegrass<br>White clover |
| 2 | Bluegrasses<br>Red top<br>White clover | Bluegrasses<br>R. I. bent<br>White clover | Bluegrasses<br>R. I. bent<br>White clover |
| 3 | | R. I. bent<br>White clover | R. I. bent<br>White clover |
| 4 | | R. I. bent<br>Sweet vernal<br>White clover | R. I. bent |
| 5 | | Sweet vernal | |
| 6 | Poverty | Sweet vernal<br>Poverty | Poverty |
| 7 | Poverty<br>Goldenrod<br>Broom sedge<br>Cinquefoil<br>Trees | Poverty<br>Goldenrod<br>Broom sedge<br>Cinquefoil<br>Moss<br>Ferns<br>Trees | Poverty<br>Cinquefoil<br>Moss<br>Ferns<br>Trees |

In more acid soils the available nutrients which have accumulated in their surfaces are soon exhausted and Kentucky bluegrass, which requires a relatively high-fertility level, is soon succeeded by plants tolerant of a lower fertility level. The succession of plant associations

which occur during the depletion of pasture soils in New York may be arbitrarily grouped as shown in Table 9. It is believed that Kentucky bluegrass does best where $NO_3$ is readily formed. Rhode Island bent grass grows well on relatively poor acid soils in humid climates and it apparently uses $NH_3$ to good advantage. It is kno that drying a soil may greatly decrease its $NH_3$ content. Some may be oxidized to $NO_3$ and some may volatilize, since $NH_3$ is volatile hydride.

Subrahmanyan (77, 78) suggests that $NH_3$ may be formed in a wet soil by a deaminase. It is also probable that Rhode Island bent grass uses Si as a nutrient. The drying of the soil may change the Si from a hydrosol to a hydrogel and thereby lower its availability to plants. These may be factors limiting the distribution of Rhode Island bent grass to relatively cool moist climates.

Table 9 shows that there is a more or less definite succession of plant associations on pasture soils. The first association is apt to be bluegrasses and white clover. This will be followed by an association of bluegrass, bent grass or red top, and white clover. As the soil is gradually depleted the associations pass through the bent grass, sweet vernal grass, and poverty grass associations to the final weed and tree associations. These definite associations reflect different fertility levels. Pastures containing the lower or final associations can be improved only by fertilization. Unless this is done the cutting of the weeds and trees in such pastures is of little value.

Data by Godden (25) presented in Table 10 indicate that it is desirable to have a well-balanced ratio of nutrients in pasture plants. The fertilizer nutrients which have relatively high standard electrode potentials, such as Ca, K, and P, usually give greatest growth response. However, it should not be overlooked that the strong ions or those relatively high in the potential series are often selectively absorbed and may limit the intake of weaker necessary nutrient ions, such as Mg, Mn, and Fe.

TABLE 10.—*Comparison of the mineral content of two very poor and a very rich pasture and the average for cultivated pastures.**

| Type of pasture | CaO % | $P_2O_5$ % | $Na_2O$ % | $K_2O$ % | Cl % | N % | $\frac{K_2O}{CaO}$ |
|---|---|---|---|---|---|---|---|
| Island of Lewes: | | | | | | | |
| Eaten | 0.286 | 0.243 | 0.377 | 0.678 | 0.115 | 1.340 | 2.4 |
| Not eaten | 0.295 | 0.177 | 0.379 | 0.540 | 0.102 | 1.029 | 1.8 |
| Falkland Islands | 0.225 | 0.488 | 0.290 | 1.980 | 0.580 | 1.650 | 8.8 |
| Taplow pastures, good | 2.473 | 0.997 | 0.698 | 2.398 | 0.498 | 3.562 | 1.0 |
| Average for cultivated pastures | 1.004 | 0.735 | 0.246 | 3.177 | 0.950 | 2.830 | 3.2 |

*After Godden (25).

Hughes (32, 33) has pointed out that the weaker ions form compounds which are more sensitive to light or electrical radiation. The presence of weaker ions may greatly facilitate the photosynthetic processes. Laboratory experiments conducted by Baly (3) on the synthesis of carbohydrates from carbonic acid are of special interest in this connection. With the technic employed he did not bring about the synthesis of carbohydrates in the presence of the alkali metals, but when $MgCO_3$, $Al_2(CO_3)_3$, and $ZnCO_3$ were radiated with

ultra-violet light he produced considerable quantities of carbohydrates. The carbonates of the nobler metals, such as Ni and Co, on exposure to visible light from an ordinary tungsten filament lamp gave a larger yield of carbohydrates than either $MgCO_3$, $Al_2(CO_3)_3$, or $ZnCO_3$ ultra-violet light.

These results and the response of both plants and animals to some of the relatively weak ions such as Mg, Mn, Cu, Fe, Ni, Co, I, and others, as observed by Allison, et. al. (2), Garner, et al. (20), Gilbert and McLean (22, 23), McHargue (49), Hudig (31), Schreiner and Dawson (64), Skinner and Reid (70), Titus and Cave (80), Chidester, et al. (11), and Russell (61), definitely suggest that the presence of compounds of these weak ions may be very important in the nutrition of both plants and animals. The effects of such compounds may be partially due to their sensitivity or the absorption of visible light radiation. The readiness with which such compounds undergo a change of valence may be an important factor in determining their physiological effects. In Table 10 it is observed that the pasture plants from the Falkland Islands contained 8.8 times as much potash as lime. It is interesting to note that there is a high mortality among sheep on these Islands. On the rich Taplow pastures the lime slightly exceeds the potash. The averages for the cultivated pastures show that there is about 3 times as much potash as lime in the plant. The lack of a proper balance of mineral content of pasture plants may greatly affect the nutrition of animals.

## GROUPING CROPS ACCORDING TO THEIR GROWING SEASON

The selection of a desirable combination of pasture plants is an important consideration in the economical management of pastures. It is necessary to know the seasons of the year at which the various pasture plants make their most rapid growth. This is shown in Table 11. It may be seen that there are only a few common permanent pasture plants which grow well during late July and early August. Rhode Island bent grass, creeping bent grass, and sweet clover may supply an abundance of forage during this critical pasture

TABLE 11.—*Best pasture plants for various seasons of the year.*

| Period | Relative production of plants for each period: Permanent pasture | Rotation pasture |
|---|---|---|
| May | Kentucky bluegrass, rough stalk meadow grass, white clover, orchard grass, sweet vernal grass, red fescue | Sweet clover, winter rye, and vetch (on sandy soils) |
| June | Kentucky bluegrass, rough stalk meadow grass, white clover, Canadian bluegrass, red top, red fescue | Sweet clover, rye, oats and peas |
| July–Aug. | Rhode Island bent grass, white clover, creeping bent grass, | Sweet clover, oats and peas, sweet sorghums, millets, orchard grass; hay field after haying |
| Sept.–Nov. | Rhode Island bent grass, creeping bent grass, white clover, Kentucky bluegrass | Sweet clover, sweet sorghums, millets, hay fields |

period. Therefore, it is easy to understand why the intensive dairy sections in New York should be confined to regions having conditions suitable for the growth of any one or all three of these important pasture plants. Since Rhode Island bent grass is very sensitive to low rainfall and sweet clover is sensitive to acid soil conditions, these important pasture plants are restricted to definite sections of the country.

## SUMMARY

1. It has been observed that there is not a close correlation between the H-ion concentration of the soil and the growth of pasture plants. It is believed that the quantity and quality of the exchangeable cations in the soil complex may be more important than the pH value of the soil in determining its adaptability for the growth of certain plants.

2. Recent work on cation exchange in soil colloids shows that there is a correlation between the exchangeability of the various cations and the standard electrode potentials of the metallic materials. Relatively more cations are removed by extraction with normal $NH_4Cl$ than by electrodialysis. This difference is probably partially due to the relative solubilities of the hydroxides of the various metals in water and in the presence of $NH_4$ salts.

3. Numerous investigators have reported data which illustrate the fact that there is a general correlation between the initial or qualitative order of absorption of nutrient ions by organisms and the electromotive series. There are some data which suggest that certain plants or specific tissues selectively absorb isosteric ions. The $NO_3$ and $H_2PO_4$ anions are relatively strong anions which are sensitive to visible light radiation. The sensitivity of compounds to visible light may be an important factor in nutrient media. It is probable that there is a closer correlation between the growth of plants and the ratio of colloidal material to the available reactive metals which have relatively high standard electrode potentials than there is between the actual percentage of these materials in the soils and plant growth.

4. There is a correlation between the chemical composition of the ash of pasture plants and the available soil constituents. Pasture plants grown on poor acid soils usually contain smaller amounts of material with relatively high standard electrode potentials than plants grown on productive soils. The plants grown on the poor acid soils often contain relatively large amounts of Si and other hard elements with relatively low standard electrode potentials, such as Al, Mn, and Fe. It is believed that the presence of the hard elements influences the palatability of the pasture plants. The plants grown on the fertile soils usually contain relatively large amounts of the soft elements, such as P, K, and Ca, and are usually palatable.

5. There is a more or less definite succession of plant associations accompanying the depletion of pasture soils. The depleted condition of the soil is probably reflected in the ash content of the plants. The width of the N:C ratio of the organic matter on and in the soil is correlated with the relative amounts of cationic and anionic N avail-

able for plant growth. Soils with high nitrifying power apparently produce a better quality of pasture than soils with low nitrifying power.

6. The response of both plants and animals to some of the relatively weak ions, such as Mg, Mn, Cu, Fe, Ni, Co, I, and others, definitely suggests that the presence of compounds of these weak ions may be very important in the nutrition of both plants and animals. The sensitivity of such materials to light radiation and the readiness with which such compounds undergo a change in valence may be important factors in determining their physiological effect.

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## DISCUSSION

The study of soils and flora relationships has reached the point where the present H-ion concentration determination raises some questions. Has this method of soil and plant study passed its usefulness? Can it be modified to meet still further demands, or is it best to discard it for something more exact?

The electrolytic study of the availability of certain elements has opened up a field of seeming extreme importance in plant research work. The necessity for more exact knowledge of plant and soil reactions is daily apparent and this paper opens a way.

In connection with the work on succession of plants on pasture lands, the availability of plant nutrients assumes an importance in pasture fertilization work that has heretofore been overlooked. The relation of the plant needs to the form of nitrogen most advantageously used by those plants gives the basis for proper fertilization of plant associations under the various conditions noted, and what might be a heavy specific application under one set of conditions would not be suitable under another.

Pasture surveys, such as those reported from New Jersey and those reported previously in this JOURNAL from New York, have an important bearing on this subject. In spite of the succession of pasture plant associations accompanying the depletion of some pastures soils, certain studies have shown that there is little deterioration of pastures which are used to capacity even though they are located on very different soils. This is indicated by the total food nutrients supplied by pastures.—M. F. ABELL, *New Hampshire College of Agriculture.*

# 5. THE HOHENHEIM SYSTEM[1]

Kaspar Peter[2]

In discussing the Hohenheim System, or as the English refer to it, "The New System of Grassland Management," we may make clear at the beginning the four main points involved in this system, *viz.*, (1) dividing the pasture area into different smaller plats, (2) dividing the grazing herd according to production, (3) frequent rotation of these groups of cattle, and (4) intensified fertilization with more attention to high nitrogen applications.

When the pasture is prepared for the season, the question arises of how to utilize the pasture in order to get the highest returns. Here we reach one of the most important parts of the "Hohenheim System." The average farm has one or two plats where the stock grazes during the season. The entire herd and perhaps horses and sheep are running on one of these plats as long as they possibly can find some food. If the grass is too short, the barn feeding begins. It is surprising what large quantities of concentrates many farmers feed during the summer months. About the same conditions existed in Germany up to the war. With the war on and cut off from all outside sources, Germany had to find means to supply stock with feed on her own land. It was Professor Warmbold who first introduced at the Agricultural College at Hohenheim a new system of grassland management. The whole area of the Hohenheim pasture was divided into many plats; and with the larger number of plats, it was necessary to increase the frequency of the rotation of the herd on these plats. Every up-to-date dairy farmer long ago made it a practice to feed his stock according to the production, at least during the winter months when the stock is fed entirely in the barn. Why should it be different during the summer months when the stock is on pasture?

According to the most practical and economical system of feeding in the barn, therefore, the herd was divided into three groups during the pasture season also. These groups included, first, high producing cows; second, low producing cows; and third, dry stock, horses, etc. Grass high in protein can fully, or at least to a great extent, take the place of high priced concentrates. Considering this, we give to our higher producers the grass which is richest in protein. We therefore bring this group of cows first on the plat which has the best stand of grass. After a few days we move this first or high-producing group to a second plat, where again they may obtain young and fresh grass. The second group of low-producing cows then occupies the plat which the high-producing cows left. It is reasonable that in just a few days the first group of cows cannot clean the plat entirely and there is plenty left to feed the second group very well. After the latter are off, there is still enough for the dry cows and young stock. By this system of rotation the high-producing cows have higher protein and more digestible food and can find it in a shorter time and

[1]Paper read as part of the symposium on "Pasture Management Research" presented at the joint session of the New England Section of the Society and Section O of the A. A. A. S. held in New York City, December 28, 1928.

[2]Synthetic Nitrogen Products Corp., 285 Madison Ave., New York City.

more easily on a smaller area. The dry stock has more time and more energy to spend in cleaning up the rest and keeping the pasture as short as necessary for harrow treatment.

Grass well fed with fertilizer will grow quicker in the spring and there is the danger that on some plats the grass may become too high and too stalky before the cattle can be brought on the plats for grazing. In order to prevent waste, some plats may be reserved for mowing, and not before the first half of July should these plats be used for additional pastures. This method gives a chance to meet the different weather conditions and besides provides for hay high in digestible protein. These hay plats should be cut at short intervals one after the other and in a very early stage of vegetative development thus furnishing hay which is much better in its chemical composition than the average.

The crop of our pastures is the yield of milk or the growth and gain in live weight of the animals in which crop we take away a larger proportion of nitrogen than of phosphoric acid and potash. When planning pasture fertilization we should consider the aforementioned fact.

Many experiments show that owing to intensive fertilization with nitrogen, the percentage of protein as well as the digestibility of grasses are greatly increased and fibre is reduced. There is, therefore, not only an increase in yield, but also an improvement in quality due to fertilizer. This is a fact which is very important in the management of pastures. While the average hay contains up to 12% protein, Professor Neubauer has by fertilization increased the percentage to 23, and Professor Fingerling obtained as much as 26 and 28%. This was under European conditions, but experiments at Amherst, Mass., also showed about the same percentage. Throughout the entire season the average protein content on fertilized plats was 17.94% as compared with 13.67% on the check plat.

Here it may be mentioned that Professor Raum of Weihenstephan has proved that nitrogen given in the form of fertilizer to grassland was returned by 62% when the grass was cut twice, by 75% when cut three times, and by nearly 100% when cut four or five times. In the new pasture management system, the grass is cut not only three or four times, but, in proportion to the number of pasture plats, about five or six times. Therefore, fertilization of pastures appears in a very favorable light.

During the season the pasture plats at Amherst received 85 pounds of nitrogen, 55 pounds of phosphoric acid, and 67 pounds of potash in the form of Nitrophoska 2 of 16.5–16.5–20, and were top-dressed three times with Calurea containing 34% nitrogen. A total of 334 pounds of Nitrophoska and 90 pounds of Calurea was applied per acre.

Besides this fertilization, careful attention should be given to other pasture treatments. The pasture should be harrowed in the spring in order to aerate the soil. Also it should be harrowed occasionally during the season and especially at the end of the season in order to distribute the mole hills and most of the droppings so as

to eliminate rank grasses. By neglecting this rank grass more grass is wasted on pasture than is generally realized. Studies have shown that on some pastures up to 45% of the yield is lost over the period of a few seasons. After harrowing in the spring, it is a good practice to go over the pasture with a very heavy roller in order to harden the ground, increase capillarity, stimulate vegetation, and close the sod.

TABLE 1.—*Summary of plats in pasture experiment, Massachusetts Agricultural College, 1928.*

| Plat No.* | Pasture days† Milch cows | Dry stock | Pounds of milk produced | Pounds of hay calculated to 12% moisture |
|---|---|---|---|---|
| 1 | 1,407 | 822 | 34,714 | |
| 2 | 1,081 | 589 | 26,698.3 | |
| 3 | 1,086 | 518 | 27,683.7 | |
| 4 (check) | 412 | 453 | 10,623.7 | |
| 5 | 958 | 882 | 21,512 | |
| 6 | 1,010 | 705 | 25,881.3 | |
| 7 | 370 | 277 | 9,121.1 | 34,914 |
| 8 | 600 | 188 | 15,583.8 | 20,307 |
| 9 | 312 | 217 | 8,007.6 | 16,816 |

*All plats were 8 ¼ acres.

†Any day the cows were on a plat was called a pasture day for each cow, irrespective of the number of hours.

TABLE 2.—*Cost of operation in pasture experiment, Massachusetts Agricultural College, 1928.**

| | Fertilized plats‡ | Check plat 4 |
|---|---|---|
| Expenditures: | | |
| Feed | $413.09 | $135.05 |
| Fertilizer | 174.40 | —— |
| Field costs | 52.88 | 36.04 |
| Land rental, 8% ($150 per acre) | 99.00 | 99.00 |
| | $739.37 | $270.09 |
| Credits: | | |
| Pasturage of Group III (dry cows) at 7½c. per day† | $ 52.73 | $ 33.98 |
| | $686.64 | $236.11 |
| Milk produced, pounds | 27,698 | 10,624 |

*Average for plats 1 to 6 which were used for grazing exclusively.

†Based on current prices for pasture in Massachusetts.

‡Average of plats 1, 2, 3, 5, and 6.

TABLE 3.—*Summary per acre of plats used for grazing exclusively in pasture experiment, Massachusetts Agricultural College, 1928.*

| Plat No. | Pounds of milk produced | Increased production per acre as compared with check, pounds |
|---|---|---|
| 1 | 4,693 | 3,405 |
| 2 | 3,236 | 2,948 |
| 3 | 3,355 | 2,067 |
| 4 (check) | 1,288 | —— |
| 5 | 2,607 | 1,319 |
| 6 | 3,137 | 1,849 |
| Average | | 2,317 |

| | |
|---|---|
| Average receipts above cost of feed in Massachusetts Herd Improvement Assoc. (2,000 cows), per cwt. | $ 2.55 |
| Average gain per acre on fertilized plats: | |
| Average increase in pounds of milk produced | 2,317 |
| Receipts above cost of feed | $59.08 |
| Cost of fertilization per acre | $23.46 |
| Net gain above feed and fertilizer cost | $35.62 |

This gives, in brief, an idea of the conduct of the Hohenheim System. Before applying this system on the average farm each farmer will be justified in asking, "What benefits can I expect for the increase in labor and the higher expenditures involved by intensifying my pasture management?"

The splendid success of the "New System of Pasture Management" which means a combination of fertilization, treatment, and management may be shown by practical examples.

At Hohenheim, Professor Warmbold increased the pasture days from 300 to 860. A "pasture day" is understood to be a day spent on pasture by one cow with a live weight of 500 kilos. The production of milk per hectare (2½ acres) was raised from 5,100 to 10,200

TABLE 4.—*Pasture demonstration, Grand Isle, Vt., 1928.*

| | Fertilized plat* | Check plat* |
|---|---|---|
| Materials used per acre: | | |
| Nitrophoska No. 1, | | |
| 265 pounds | 40 lbs. N, 80 lbs. $P_2O_5$, 40 lbs. $K_2O$ | — |
| Calurea, 132 pounds | 45 lbs. N | |
| Number of pasture days: | | |
| Milch cows | 709 | 187 |
| Dry cows | 178 | 45 |
| Total pasture days | 887 | 232 |
| Number of times pastured | 6 | 5 |
| Pounds of milk produced | 18,409 | 4,813 |

*6.75 acres.

TABLE 5.—*Receipts and expenditures in pasture demonstration, Grand Isle, Vt., 1928.*

| | Fertilized plat | Check plat |
|---|---|---|
| Receipts: | | |
| Total milk @ 50c per lb. butter fat, 50c per 100 lbs. skimmilk (average test 3.75%) | $425.70 (18,409 lbs. milk) | $111.24 (4,813 lbs. milk) |
| Pasture day dry stock @ 5c per day | $ 8.90 | $ 2.25 |
| Total receipts | $434.60 | $113.49 |
| Expenditures: | | |
| Additional feed: | | |
| Grain @ $52 per ton | $ 89.25 ( 3,425 lbs.) | $ 24.00 ( 923 lbs.) |
| Silage @ $8 per ton | $ 42.92 (10,730 lbs.) | $ 9.25 (2,312 lbs.) |
| Green feed @ $6 per ton | $ 1.20 ( 400 lbs.) | $ 2.64 ( 880 lbs.) |
| | $133.37 | $ 35.89 |
| Fertilizer: | | |
| Nitrophoska @ $100 per ton | $ 89.45 ( 1,789 lbs.) | — |
| Calurea @ $100 per ton | $ 44.55 ( 891 lbs.) | — |
| Distributing fertilizer @ $2.26 per acre | $ 15.26 | — |
| | $149.26 | |
| Total Expenditures | $282.63 | $ 35.89 |
| Net Gain | $151.97 | $ 77.60 |

pounds during one pasture period; and while in previous years 0.56 hectare was necessary to carry one animal of 500 kilos, only 0.21 hectare was required to keep an animal after the "New System" was introduced. In addition, of 28 hectares in pastures, only 12 were used for pasturage up to the end of June while the other 16 were used for haymaking.

Similar experiments were carried on in England, where the system was introduced three years ago, and covered last year about 1,000 acres of pastures. For instance, on the Tollesby Farm in Maraton, County York, the average number of cows maintained on 27 acres was 46. The total number of grazing days provided was 8,564, equal to 1 cow per 0.58 acre; as compared with 2,885 grazing days previously, equal to 1 cow per 1½ acres. The National Institute for Research in Dairying started the intensified system in 1925 and makes the statement that during the season of 1927 the pasture plats provided 1,633 pasture days and produced 27,268 pounds of milk, as compared with 1,112 pasture days and 17,984 pounds of milk from the check plat.

Tables 1 to 5, inclusive, show the results of pasture experiments carried on at the Agricultural College at Amherst and one conducted on the farm of J. B. Hoag at Grand Isle, Vt., under the supervision of Professor Van Alstine and County Agent Painter.

In many cases we have not only an increase in yield, but also a saving of concentrates, which makes the dairy farmer more independent of outside markets and dairy farming more profitable.

## DISCUSSION

A system for intensive pasture production must meet two tests, *viz.*, Will the cost for a given quantity of pasture grown be less than when grown on a larger acreage at a lower cost for each acre? If the cost for a given quantity is greater, Will the pasture be enough better in quality to justify the additional expense?

To be practical the Hohenheim system must also meet another test. It must be superior to a number of other systems of intensive pasture production.

A system that may be practical in western Europe may not be practical here. We still have and probably will have for a long time, an abundance of land available for pasturage. New England has 46.8% more land in pasture than in all other crops; New York has only 18.5% more land in other crops than in pasture; Pennsylvania has 45.8%; New Jersey, 70.2%. There are 5.94 acres of pasture land for each animal unit in New England, 3.88 acres in New York, 3.32 acres in Pennsylvania, and 2.17 acres in New Jersey. Germany has 343 persons for each square mile and Great Britain has 383, while New England has only 111; New York, 211; and Pennsylvania, 194. Labor costs are lower in Europe, machinery is used less.

Much of the land now in pasture in this country is not suitable, because of topography or stoniness, for the harrowing and frequent fertilizer applications required in the Hohenheim system. It is probable that most of the land which can be improved by the Hohenheim system is also suitable for sweet clover and other pasture plants which require seeding.

The Hohenheim system requires an annual expenditure of approximately $20.00 per acre for fertilizer materials, four fertilizer applications, liming at intervals, three or four harrowings, and a large amount of fencing. The total cost for the annual care alone must be $30.00 per acre. The same investment will almost seed an acre to sweet clover which will support four to six cows for a season and a half and then one cow for five years or more without additional expense. The same investment will treat two acres with mineral fertilizers and lime. It has maintained an animal per acre for five years in the Storrs experiment and there is promise of continued response for several more seasons.

While the hay secured from the fields not pastured in the spring might be of good quality, Would not the expense of four or five cuttings before July, in addition to the cost of the nitrogen, make it more costly than clover or alfalfa?

The superiority claimed for the Hohenheim system during drought needs consideration. Has it not been shown that a surface covered with growing vegetation loses water faster than a bare surface? Sweet clover is affected little by drought and sweet clover, alfalfa, or red clover might be used to supplement permanent pastures in late summer.

Is manure of special benefit because of the plant nutrients or the organic matter it contains? Would not much of the organic matter be lost when applied to the surface? There appears to be no difficulty in maintaining a good growth of pasture plants without it.

The "enemies" of clover do not appear to prevent luxuriant growth when soil conditions are favorable. There may not be a larger percentage of clover because the amount present furnishes so much nitrogen that grasses compete too severely. Harrowing, except to re-establish seedings, is of questionable value.

Since no literature citation was included with the paper under discussion, it has been impossible to verify the origin of many statements.—J. S. OWENS, *Extension Agronomist, Connecticut Agricultural College, Storrs, Connecticut.*

## 6. PASTURE INVESTIGATIONS IN THE SOUTHEASTERN STATES[1]

H. N. VINALL[2]

### INTRODUCTION

In discussing this subject I have considered the southeastern states as those south of the Ohio River and east of Texas and Oklahoma, thus including Maryland, Virginia, Kentucky, Tennessee, North Carolina, South Carolina, Georgia, Florida, Alabama, Mississippi, Louisiana, and Arkansas. Much of this vast territory is situated in the cotton belt, but the northern part is known as the corn and winter wheat belt, according to Dr. Baker of the U. S. Dept. of Agriculture, and the southernmost part as the subtropical coast belt. Only in the corn and winter wheat belt are pasture conditions and pasture plants anything like those of the northern states.

The soils of these states are varied and not as uniformly productive as are those of the corn belt. In the Coastal Plain particularly, the drainage is often inadequate and much of the land is inclined to be sandy. The Piedmont soils, on the contrary, are nearly all well drained and for the most part clays or clay loams. In addition there are considerable areas of alluvial or silt soils, especially in the Mississippi Valley.

The climate of these states is in the main favorable for a maximum production and utilization of pasture. The growing season is long and the rainfall adequate, except for short periods of severe drought during the summer months. The first efforts to improve the pastures in this region were made with northern grasses and these failed completely, except in Maryland, Virginia, Kentucky, Tennessee, and western North Carolina. Outside of these states livestock farming was not important and until recently there was no popular demand

[1]Paper read as part of the symposium on "Pasture Management Research" presented at the joint session of the New England Section of the Society and Section O of the A. A. A. S. held in New York City, December 28, 1928.

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for more and better pastures. In the Gulf states particularly, numerous difficulties have beset the livestock industry. The Texas fever tick was widespread and has not yet been entirely eradicated; internal parasites are abundant; much of the uncultivated land is or was timbered; and above all, the demand has been for a cash crop owing to the character of farm labor. It is small wonder, therefore, that state experiment stations have been able to devote little time or attention to pasture investigations. Within the last 10 years there has been evident a new interest in livestock production and a consequent public demand for information on pasture improvement. Because of the tardy beginning of pasture investigations in the Southeast, this review must be considered as a report of prospective rather than actual accomplishment.

The work being done may be classed as plant adaptation tests, experiments in the establishing of improved pastures, carrying capacity tests, fertilizer tests, and demonstration of improved pastures.

## PLANT ADAPTATION TESTS

The most extensive tests of new pasture plants have been in progress under cooperative arrangements between the Office of Forage Crops, U. S. Dept. of Agriculture, and the Florida Experiment Station at Gainesville, Fla.; the Coastal Plain Experiment Station at McNeill, Miss.; and the Georgia Coastal Plain Experiment Station at Tifton, Ga. At Gainesville, Fla., over 300 different species of grasses and many legumes have been tested in nursery rows and the better ones in small plats. These tests have definitely established the value of carpet grass, Bahia grass, and centipede grass on the Norfolk sands of this section. An interesting experiment in which a considerable number of grasses were planted side by side in narrow plats to test their aggressiveness under pasture conditions at Gainesville is shown in Fig. 1.

In this planting of the series of grasses, including carpet (*Axonopus compressus*), Bermuda (*Cynodon dactylon*), St. Augustine (*Stenotaphrum secundatum*), Bahia (*Paspalum notatum*), giant Bermuda (*Cynodon dactylon* var. *maritimus*), golden beard (*Andropogon monticola*), giant carpet (*Axonopus furcatus*), centipede (*Eremochloa ophiuroides*), St. Lucie (*Cynodon dactylon* var.), dallis (*Paspalum dilatatum*), and blue couch (*Digitaria didactyla*) grasses, the centipede grass proved to be by far the most aggressive with carpet next, St. Augustine third, and Bahia fourth. Blue couch grass barely maintained itself but did not spread beyond the original plat lines.

At McNeill, Miss., on a somewhat heavier soil than at Gainesville, Fla., 380 different species of grasses and numerous legumes have been under test. Here, too, carpet grass and centipede grass have appeared as the most dependable grasses for pasture improvement. Lespedeza does well at this point and should be used in combination with the grasses. The remarkable ability of centipede grass to establish itself on the native grass sod and spread by means of its creeping stolons on very poor stony hillsides is illustrated in Fig. 2.

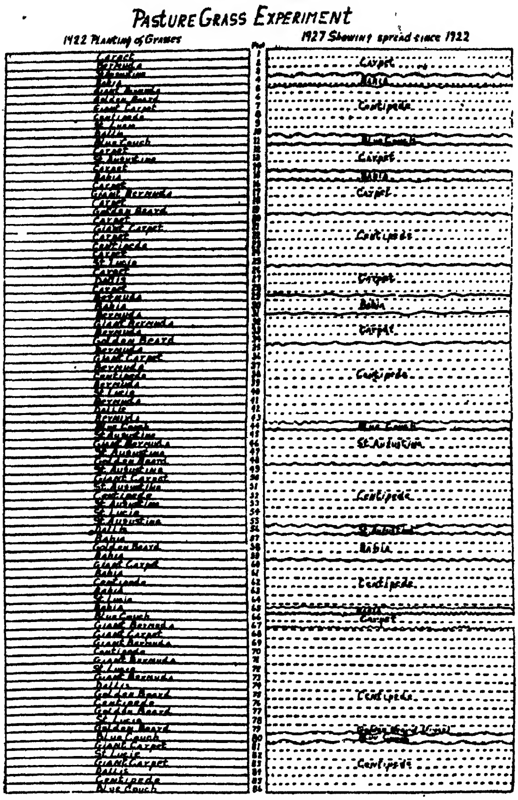



FIG. 1.—The aggressiveness of different pasture grasses. Centipede grass shows an unusual ability to spread in competition with other grasses at the Florida Experiment Station, Gainesville, Fla.

FIG. 2.—The peculiar resemblance of the stolons of centipede grass to a centipede indicates the reason for its common name.

At Tifton, Ga., on representative Tifton soil, 135 different species of grasses and legumes have been tested. A considerable number were also under test at the State College of Agriculture at Athens, Ga., and a lesser number on the Iberia Livestock Farm, Jeanerette, La., and at West Point, Miss. Less extensive tests have also been made individually by experiment stations in other states.

This spring the Office of Forage Crops, in cooperation with the South Carolina Agricultural Experiment Station, established a grass garden on the Sandhill Experiment Station near Columbia, S. C. (Fig. 3). In this small grass nursery there are 50 different species of grasses and 18 legumes under test. Some of these look decidedly promising for this extremely sandy soil which is a sandy phase of the Norfolk sand.

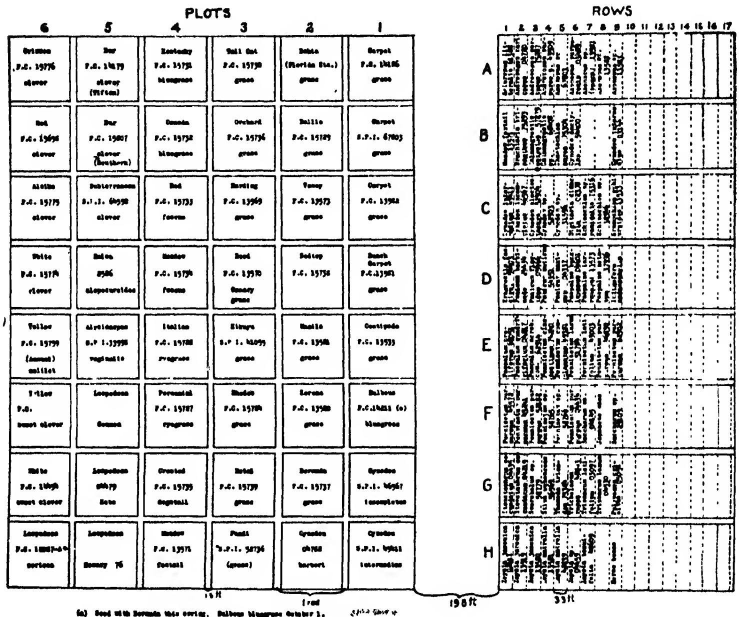



FIG. 3.—Chart showing arrrangement of the grass garden at the Sandhill Experiment Station, Columbia, S. Car., in which is being tested the adaptation of new grasses and legumes. Left, square-rod plats; right, rod rows. Room expansion of both.

## PASTURE IMPROVEMENT STUDIES

Methods of establishing improved pastures have been studied at the Experiment Station at Gainesville, Fla. Several of the most important grasses, such as carpet grass, Bahia grass, and dallis grass, were seeded each month of the year for several years. A comparison was also made of seeding and planting vegetatively the grasses on native sod without any preparation except clearing off the brush and trash as compared with seeding on land which had been disked or plowed first. A good turf was obtained much quicker

when seeding followed adequate preparation of the soil. Stands would thicken up after several years under favorable conditions, however, without any seedbed preparation.

At Tifton, Ga., and McNeill, Miss., experiments in establishing centipede grass vegetatively seem to show that broadcasting chopped sod or stolons and covering with a disk is not likely to prove successful. The most successful method is to set small pieces of sod in a furrow, partially cover these pieces, and afterwards tramp the soil about them.

At the Sandhill Station, Columbia, S. C., the Office of Forage Crops is attempting the establishment of a 90-acre pasture for the accommodation of a dairy herd which will be placed there in the near future by the Bureau of Dairy Industry. On this area of newly cleared land carpet grass, Bahia grass, lespedeza, and white clover were seeded last spring on the low, moist land and Bermuda grass and lespedeza on the upland and hillsides. When the grasses and legumes have become established some tests of fertilizers and carrying capacity will be undertaken.

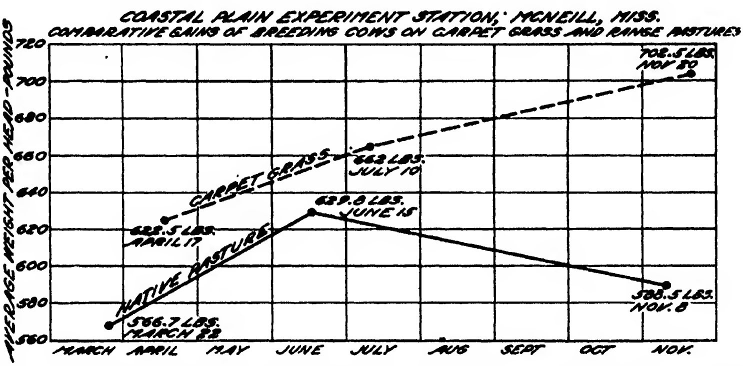


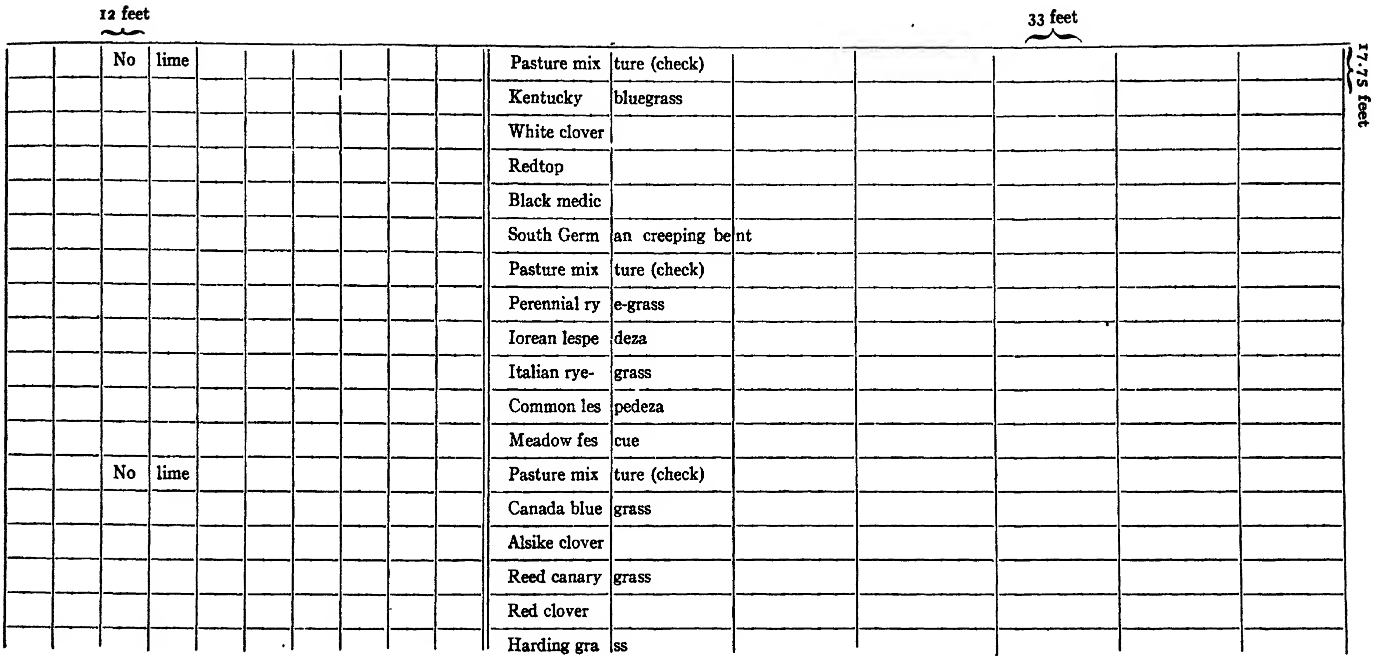

FIG. 4.—Graph showing the gains made by cattle on a carpet grass pasture as compared with gains on range pastures at McNeill, Miss. (By S. W. Greene, Supt., Coastal Plain Experiment Station.)

At the Experiment Station at Starkville, Miss., splendid pastures have been produced by a combination of Bermuda grass, dallis grass, and lespedeza. White clover, where present, is advantageous.

At the Iberia Livesock Farm, Jeanerette, La., it has been demonstrated that Bermuda grass pastures may be made highly productive by mowing them several times during the year to insure young succulent grass which is not only greatly relished by the animals, but is more nutritious.

The Virginia Experiment Station is studying the improvement of hillside pastures by terracing, fertilizing, and seeding. They report the successful establishment of good pastures in this way on land which formerly produced nothing. Small plat tests of fertilizers on pasture grasses are also in progress at the Virginia Station.

At the Central Tennessee Experiment Station, Columbia, Tenn., studies are being made on the methods of management of bluegrass and of orchard grass pasture.


12 feet
33 feet
17.75 feet
No lime
Pasture mixture (check)
Kentucky bluegrass
White clover
Redtop
Black medic
South German creeping bent
Pasture mixture (check)
Perennial rye-grass
Iorean lespedeza
Italian rye-grass
Common lespedeza
Meadow fescue
No lime
Pasture mixture (check)
Canada bluegrass
Alsike clover
Reed canary grass
Red clover
Harding grass

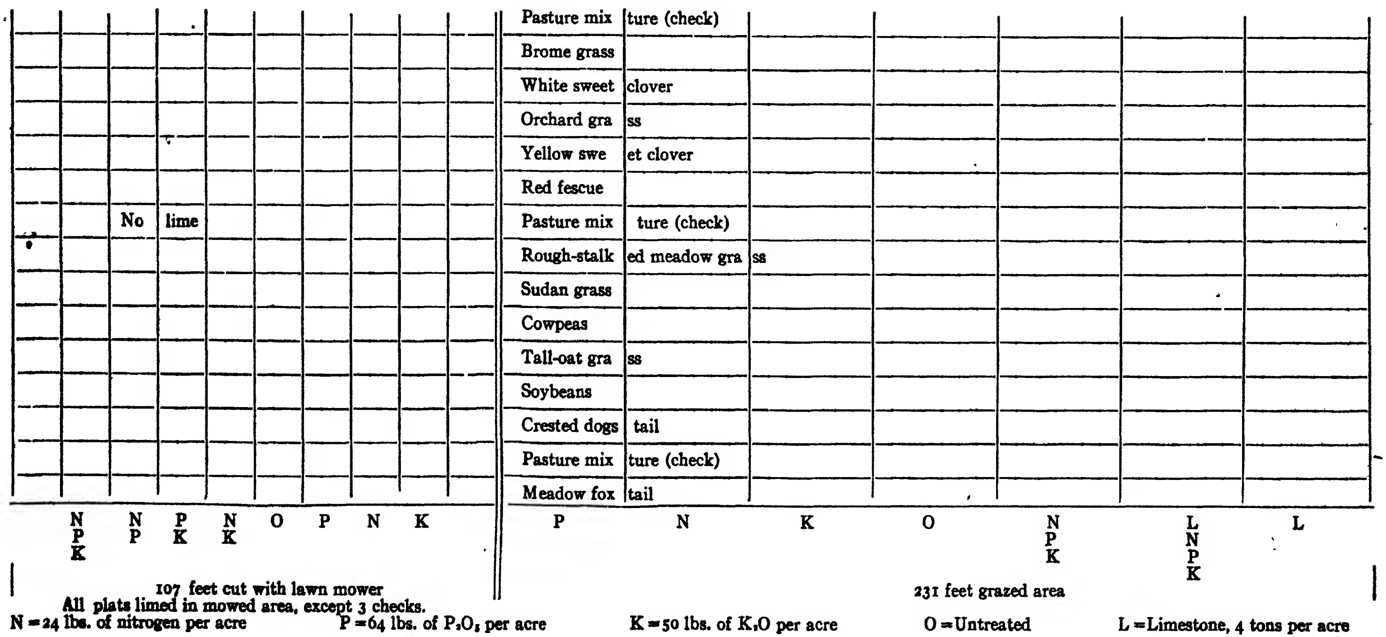



FIG. 5.—Diagram of an experiment at Beltsville, Md., designed to determine the yield and palatability of a large number of pasture plants.

At the Branch Experiment Station, Stutgart, Ark., the improvement of pastures by the use of Bermuda grass, redtop, and lespedeza is being investigated. Other grasses have been tested without success.

## CARRYING CAPACITY AND PRODUCTIVENESS

The carrying capacity and productiveness of carpet, Bahia, Bermuda, and centipede grasses in pure stands and of carpet, Bahia, and Bermuda grasses in mixture are being investigated by actual grazing trials at the Florida Experiment Station.

At the Georgia Coastal Plain Experiment Station, Tifton, Ga., carrying capacity tests will be inaugurated next spring on an old carpet grass pasture. Actual grazing tests at different rates per acre will be made on fertilized and unfertilized pasture. Plans have also been made to begin in 1930 some grazing experiments with temporary pasture plants on the upland. These tests will determine the pasture value of winter legumes, such as hairy vetch, Monantha vetch, and the Austrian winter pea. These winter-growing legumes will be plowed down in the late spring and followed by a summer crop, such as lespedeza or Sudan grass, providing thus almost year-around pasture.

At the Coastal Plain Experiment Station, McNeill, Miss., it has been found that 2 acres of carpet grass pasture will carry one animal unit for nine months and produce about twice as much gain as 10 acres of the native grasses. A graph (Fig. 4) prepared by S. W. Greene, Supt., Coastal Plain Experiment Station, shows that the cattle gained very well on the native pastures until June 15 and thereafter lost weight, while on carpet grass they continued to increase in weight until October, the end of the pasture season.

At the Iberia Livestock Experiment Farm, Jeanerette, La., they have found that good Bermuda pastures will carry one animal unit per acre for about nine months.

The U. S. Dept. of Agriculture, through a cooperative agreement between the Bureau of Plant Industry and the Bureau of Animal Industry, has begun at the Animal Husbandry Farm, Beltsville, Md., an experiment to determine definitely the carrying capacity and productiveness of a pasture seeded to a complex mixture of grasses and legumes. For comparison with this permanent pasture an additional area will be seeded to sweet clover and grazed with beef cattle, one plat to be grazed continuously and the other divided into two equal parts to be grazed alternately in bi-weekly periods.

On the Animal Husbandry Farm at Beltsville, Md., in addition to the grazing experiments previously mentioned, an experiment has been started which is designed to determine the palatability and yield of various pasture plants in pure stands as compared with the standard mixture used in the grazing trials. A reference to Fig. 5 will explain the plan of this experiment which includes tests of fertilizers and lime in addition to the other phases. Plats of the various grasses and legumes, about 20 rods long and 18 feet wide have been sown. The field will be divided by a cross fence and a part of each plat grazed to observe the preference of the animals for

certain pasture plants. The other part will be cut with a lawn mower at frequent intervals and yields obtained. Chemical analyses of the herbage from the different plats will be made to determine the nutritive value and mineral content.

## FERTILIZER EXPERIMENTS ON PASTURES

A number of experiment stations already have under way tests of fertilizers on pasture grasses. Most of these are conducted on small plats which are being mowed at frequent intervals to simulate grazing conditions.

The Alabama station has in progress on 21 plats replicated four times a test of nitrogen, phosphate, and potash applied in varying quantities alone and in combinations. The nitrogen is applied as nitrate of soda and ammonium sulfate in one, two, and three applications; the phosphate as superphosphate and basic slag; and the potash as muriate of potash only. Every fourth plat is a check (no fertilizer) and one-half the plats receive lime. The experiments are on land seeded to dallis grass in combination with bur clover, black medic, and white and Ladino clover.

In another experiment these fertilizers are tested on dallis grass, carpet grass, and Bermuda grass each in combination with Korean and common lespedeza.

At the Florida Station, W. E. Stokes has been testing on small plats in duplicate and triplicate applications of single elements, two elements, and a complete fertilizer. Observations are made as to increased vigor, rapidity of spread, and increased yield in comparison with unfertilized plats. Other fertilizer tests are conducted on demonstration pastures in different parts of the state.

At the Mississippi Station, J. F. O'Kelly has in progress an experiment to determine whether phosphorus and potash are needed in addition to nitrogen in pasture fertilization. The plats are seeded with a standard pasture mixture and yields are obtained by cutting with a lawn mower.

The U. S. Dept. of Agriculture has begun at Beltsville, Md., with dairy cattle a test of the Hohenheim (German) system of rotation and fertilizer pasturing. Twelve acres were seeded uniformly with a standard pasture mixture and this will be divided into six equal 2-acre plats and grazed in accordance with the Hohenheim plan, plats from one to six being grazed in rotation first with high-producing milk cows followed by young dairy stock. The field received a uniform application of 400 pounds of superphosphate and 100 pounds of sulfate of potash in October, 1928, and in 1929 will receive at least four applications of 100 pounds per acre of nitrate of soda. A plan of this experiment is shown in Fig. 6.

This system of pasture fertilization and management will be checked against 8 acres seeded with the same mixture and continuously grazed with milk cows and young stock in the same proportions as the 12 acres in the rotation pasture. Four acres of this will be fertilized with the same quantities and kinds of fertilizer applied at the same time as in the Hohenheim pasture and 4 acres will remain unfertilized.

The Kentucky station has under way at their western sub-station at Princeton, Ky., a series of fertilizer tests on land seeded to a uniform pasture mixture in 1927. Pasturing will begin in the spring of 1929. The 18 1/20-acre plats are receiving applications of superphosphate, rock phosphate, basic slag, sodium nitrate and muriate of potash in combination with lime, and superphosphate in combination with farm manure. A 20-foot strip along one end of the plats is fenced off and yields on this strip will be determined by clipping frequently with a lawn mower. The remainder of the plats will be grazed with yearling or two-year-old steers.

| PLOT 1 | PLOT 2 | PLOT 3 | PLOT 4 | PLOT 5 | PLOT 6 |
|---|---|---|---|---|---|
| Top-dressed 100 lbs.N.S. Mar.1, 1929 | Top-dressed 100 lbs.N.S. Mar. 7,1929 | Top-dressed 100 lbs.N.S. Mar.13,1929 | Top-dressed 100 lbs.N.S. Mar.19,1929 | Top-dressed 100 lbs.N.S. Mar.25,1929 | Top-dressed 100 lbs.N.S. Mar.31,1929 |
| 16-20 milk cows grazed for 4-6 days April 15-20 | 16-20 milk cows grazed for 4-6 days April 21-26 | 16-20 milk cows grazed for 4-6 days Apr.27-May 2 | 16-20 milk cows grazed for 4-6 days May 3-8 | 16-20 milk cows grazed for 4-6 days May 9-14 | 16-20 milk cows grazed for 4-6 days May 15-20 |
| 10-12 young dairy cattle grazed for 4-6 days April 21-26 | 10-12 young dairy cattle grazed for 4-6 days Apr.27-May 2 | 10-12 young dairy cattle grazed for 4-6 days May 3-8 | 10-12 young dairy cattle grazed for 4-6 days May 9-14 | 10-12 young dairy cattle grazed for 4-6 days May 15-20 | 10-12 young dairy cattle grazed for 4-6 days May 21-26 |
| Harrowed April 27 | Harrowed May 3 | Harrowed May 9 | Harrowed May 15 | Harrowed May 21 | Harrowed May 27 |
| Top-dressed 100 lbs.N.S. April 27 | Top-dressed 100 lbs.N.S. May 3 | Top-dressed 100 lbs.N.S. May 9 | Top-dressed 100 lbs.N.S. May 15 | Top-dressed 100 lbs.N.S. May 21 | Top-dressed 100 lbs.N.S. May 27 |

FIG. 6.—Diagram of an experiment at Beltsville, Md., to determine the value of the Hohenheim (German) method of pasture management. When the cows have finished, May 20, on plat 6, they are brought back to plat 1 and the changes repeated in 4- to 6-day intervals as in the first rotation.

A more extensive test is also provided in three 10-acre fields to be grazed with steers. One will have no fertilizer treatment, one will receive 1,200 pounds of rock phosphate per acre, and the third 3,000 pounds of limestone and 600 pounds of superphosphate per acre. Gains in weight of the animals will be the measure of fertilizer value in this experiment.

## DEMONSTRATIONS OF IMPROVED PASTURES

In South Carolina the Extension Service has carried out with farmers several demonstrations of the method of establishing improved pastures by seeding carpet grass and lespedeza on the Coastal Plains and Bermuda grass and lespedeza in the Piedmont section of the state.

In Georgia the State College of Agriculture has done some work in demonstrating the value of such plants as lespedeza, carpet grass, Bermuda grass, bur clover, and kudzu in the improvement of pastures and Professor Paul Tabor is author of some excellent publications describing these pasture plants and the methods of establishing and utilizing them. The Central of Georgia Railway has also made a notable contribution to pasture development in Georgia by conducting numerous demonstration pastures along their lines. In 1923, these improved pastures carried an average of 1.32 animal units per acre and in 1924 during an eight-month grazing period, 1.46 animal units per acre over a total of 1,174 acres.

The Florida Station has assisted several farmers, particularly in northern Florida, to establish improved pastures, principally of carpet grass and lespedeza. On some of these tests of fertilizers are in progress. The results have been gratifying.

## DISCUSSION

A discussion of climatic and soil conditions affecting permanent pasture work in Georgia should help in understanding Mr. Vinall's paper. At Athens, Ga., near the northern limit of cotton production in the state, the monthly mean temperature ranges from 42.5° in January to 79.0°F in July; and at Thomasville, 25 miles from the southern border of the state and near the southern limit of cotton culture, the range is from 52.5° in January and 81.4° in July. If 50° to 75°F mean monthly temperature be accepted as the range for active growth of temperate-climate crops, there are three months during the fall and three months during the spring at Athens favorable for these plants and three months during summer too hot for their growth. At Thomasville, seven to eight months during fall, winter, and spring are favorable and four to five months in summer are too hot for the common cool-climate grasses and clovers. The long hot summers are disastrous to cool-climate perennials, leaving only annuals of this type available. Warm-climate annuals and perennials able to resist winter temperatures are also available.

Another problem of temperature encountered in this region is the occasional drop of the daily mean temperature from 50° or higher to below 20° during winter or early spring. Even cool-climate crops must have a high cold resistance to endure such changes.

According to a provisional method of calculating water needs of average crops, the mean monthly rainfall at Athens and Thomasville is in excess of the needed amounts during the months from November through April. For the remaining months at Athens there is barely enough to meet the theoretical needs of an average crop, and at Thomasville there is an excess of about 25% during July and August, but a deficiency in spring and barely enough in the fall.

The hill lands of the cotton belt are not as amply supplied with water for pastures during the frostless season as most other sections in the eastern United States.

Following is a quantitative estimate of the soil topography and condition in Georgia:

| Piedmont Section (northern Georgia) | | Coastal Plain Section (southern Georgia) | |
|---|---|---|---|
| Hill soils | Bottom soils | Ridge soils | Bottom or wet soils |
| 10,800,000 acres | 1,200,000 acres | 14,000,000 acres | 7,000,000 acres |
| 80% poor | 15% poor | 90% poor | 33% poor |
| 17% medium | 35% medium | 8% medium | 33% medium |
| 3% rich | 50% rich | 1% rich | 33% rich |
| 35% cultivated | 50% cultivated | 50% cultivated | None cultivated |

Even a casual analysis of the climatic and soil conditions of Georgia will show greater possibilities of establishing permanent pastures on low moist, rich soils than on any other kind, as these soils do not suffer from droughts as quickly as the higher lands and are fertile enough to produce a good growth of grass. In recent years the Georgia State College of Agriculture has successfully promoted the development of permanent pastures on these lowlands.

For the hill lands, a plan has been made calling for three separate pastures, one of a winter hardy annual for spring grazing, one of Bermuda grass and lespedeza, the common hill pasture mixture now used for summer grazing, and one of a semi-tropical crop that will grow through the summer and be available for grazing in the fall.—PAUL TABOR, *Georgia State College of Agriculture.*

## 7. RANGE RESEARCH OF THE U. S. FOREST SERVICE[1]

W. R. CHAPLINE[2]

The continued prosperity of the range livestock industry depends upon improving and maintaining the range resource. This industry, with ranches and livestock worth nearly two billion dollars, makes use of 587 million acres of range lands or nearly one-third of the total land area of the United States. Nearly 70% of the feed for all the livestock in the 11 far western states is obtained from grazing the native forage on timber and other range land.

The productivity of national forest ranges has increased about 25% in the last 15 to 20 years through regulation and the application of improved principles developed by research. On the other hand, most other range areas have continued to decline until, on the average, they are at least 50% below their producing possibilities. The most serious situation is on the 200,000,000 acres or so of unappropriated public domain with its intermingled state and private lands which cannot now be legally controlled, and where under present over-grazing there is little chance for sustained profitable production of livestock. Furthermore, it is these lands which should be furnishing abundant feed for the critical spring, fall, and winter periods.

The western range problem is one of building a profitable industry on ranges where essential parts have been depleted, where excessive non-producing investments have been established through range depletion, and where credit has been badly crippled. Timber production must be maintained, eroded water sheds restored, other uses of the land protected, and a close coordination made between farm land and ranges. There is a wide diversity of conditions. For example, the alpine meadows and grasslands above timber line have a short growing season, yet provide excellent feed for summer use. The mountain grazing lands of the Pacific Coast have a long, dry summer season, the very period when they must grow their feed and yet be grazed. The semi-desert ranges of the Southwest, with their sparse vegetation grazed yearlong, must depend upon production of their feed during a short summer period furnishing but a scant supply of rain.

The range research of the Forest Service is largely concentrated at three stations, *viz.*, the Great Basin in central Utah, the Santa Rita Range Reserve in southern Arizona, and the Jornada Range Reserve in southern New Mexico. Work on special problems is also under way in other parts of the West.

[1]Paper read as part of the symposium on "Pasture Management Research" presented at the joint session of the New England Section of the Society and Section O of the A. A. A. S. held in New York City, December 28, 1928.

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The livestock should be managed so that best use is made of the range. The open-herding and bedding-out system of handling sheep, for example, developed by studies of management of sheep in pastures and under herd, provides for open, quiet herding throughout the day, holding the leaders and using dogs as little as possible, allowing the sheep to shade up during the heat of the day and bedding at night where night overtakes them. Very little area is covered each day, the sheep have fresh feed every morning when they leave the bed ground, and they do not run off any of the flesh which the abundant forage puts on. The increase in the grazing capacity of the range, cleaner and larger wool production, and heavier lambs have brought an increased revenue of over $5,000,000 annually to wool growers. Likewise, salting and herding methods have been developed to work the cattle out of the valley bottoms and other natural congregating places onto slopes and other normally little used areas.

Adjustments in management must be determined to correlate grazing with satisfactory timber production. Considerable damage may be done to timber reproduction, particularly western yellow pine, by cattle, sheep, or goat grazing if there is inadequate feed or water or if they are improperly handled such as where sheep are shaded up in a clump of reproduction. A similar problem exists in certain woodland pastures in the East, where the sprouts of hardwood timber species appear to be as palatable as some of the herbaceous vegetation growing in the woods and also because many farmers use the woods for shade purposes, seriously damaging timber growth.

The influence of herbaceous vegetation and its use by grazing on soil erosion, on irrigation, power, and domestic water supplies and on floods is extremely important. At the Great Basin Station in Utah, for example, an increase in the vegetative cover from an average of 16% to 40% of the soil surface reduced the surface run-off from summer rains by 55% and sediment eroded by 56%. Run-off and erosion from melting snow appeared to be affected much less by the change in the herbaceous vegetation. Though approximately 95% of the annual run-off was from melting snow, it carried only 12% of the sediment removed; while the 5% of run-off from summer rains carried 88% of the sediment eroded.

The head of Manti Canyon, which lies just south of the station, was closed to grazing in 1903 because of the serious floods which came from the canyon through the town of Manti, Utah. At one time removal of the town to another site was under consideration. For several years the water-shed was ungrazed and has been moderately grazed each year since livestock were allowed on it. Sheet erosion of slopes has been entirely controlled and most all gullies are now revegetated with practically no chance for further cutting. No serious floods have come from the canyon since 1910.

One of the worst features of floods is the enormous quantity of silt carried from the eroding slopes and rich valley bottoms along with rocks, boulders, and other debris out on to valley farm lands or into irrigation and other reservoirs. An enormous silt deposit has been made in the Roosevelt Reservoir in Arizona. Several hundred

million dollars have been invested in the now prosperous Salt River Valley which gets most of its irrigation water from this reservoir. Unless excessive silting of this important reservoir can be controlled its productive life will be materially shortened. The problem demands adequate study immediately. Vegetation can play an important part in the erosion control. Under deferred grazing and correct utilization, for example, a number of washes on an experimental area on the Santa Rita Reserve have been recaptured since 1916 from a seriously eroding condition by grasses and brush. There is also a dense stand of grama on the slopes and soil erosion is negligible.

Range forage management has been studied largely in three ways, *viz.*, (1) the study of factors of the habitat; (2) the study of individual and associated species as to their forage value, especially at different periods of the grazing season, their life history, growth requirements, other ecological relationships, and ability to withstand grazing; and (3) practical tests of planting and grazing.

Of these factors, climate is one of the most important. On a mountain range area at the Great Basin Station over twice as much forage was produced in an extremely wet year as in an extremely dry year. In determining this the vegetation was clipped the same each year. Unless the number of livestock on the range can be reduced or the season shortened in dry years, there is excessive utilization at a time when the forage can least stand it. The Southwest is subject to severe periodic droughts which may last several years at a time. Annual rainfall may fall to one-third of average. Under such conditions the stand of forage, even without grazing, may drop 60% or more from a rather dense stand and the volume on the thinner stand is greatly reduced in addition. Starvation losses of from 30 to 50% of the livestock may occur if the management has not been properly adjusted.

Soil texture, structure, and fertility all play an important part in forage production. Experiments at the Great Basin Station showed that noneroded soil was much richer than eroded soil in lime, phosphoric acid, and total nitrogen; that the water-holding capacity was greater; and that the water required by representative plants to produce a pound of dry matter was less. A great many more leaves, greater stem and leaf length, and more dry matter are produced on the noneroded than on the eroded soil, even with a notably smaller supply of water. Both the rate of improvement of the native forage stand and the ability to reseed areas artificially depends largely upon the depletion of the soil.

Approximately 600 tests throughout the West have indicated that there is little chance for improving the bulk of native range lands in their present condition by the introduction of the common cultivated forage plants. Kentucky bluegrass, timothy, and common or smooth brome have been successful in about 100 tests where soil and moisture conditions are especially favorable, such as dry meadow areas from which the vegetation has been depleted but from which the surface soil has not been removed by erosion. On moist meadow areas, especially in the Pacific Northwest, red top and alsike clover have

proved best. None of the cultivated plants have proved financially practical on the extensive relatively dry slopes. In California, however, exotic annuals accidently introduced, have largely taken control of the foothills which indicates possibilities.

More recently growth conditions and growth requirements of plants to be seeded have been more closely correlated. In connection with this about 30 valuable native species have been tested. Violet wheat grass and large mountain brome have shown unusual promise in Utah. Both of these, though bunch grasses, seed readily, produce abundantly, withstand moderately close grazing, and have increased the forage value of experimentally seeded areas 6 to 10 times.

The forage management problem is largely one of determining ways and means of improving and maintaining the important palatable native range plants. It is of utmost importance to give these plants a chance to make good vigorous growth before being grazed. The range should not be grazed until there is sufficient feed to keep livestock in a thrifty condition and to allow grazing without serious impairment of the growth and reproductive processes of the more important forage plants. Ingram found in Oregon that excessive early grazing each year caused a delay of as much as six weeks in the satisfactory development of the palatable range plants. The earliest plants which appear on the range in the spring are usually showy flowers especially high in water content and generally of low palatability. When grazing is delayed until the important forage plants have reached a height of 6 inches and until the earlier-maturing ones have flower stalks showing, there is less danger of injury to the plants, the ground has usually dried out so that trampling does not damage it, and the livestock are able to obtain a sufficient quantity of more nutritious and substantial feed.

Grazing bunch grasses closely twice or even three times in a season, provided the first grazing is late enough and the intervals are sufficient for the vegetation to recover from each cropping, ordinarily does not seriously affect the yield and vigor of the plant cover. Their correct utilization is usually somewhat under 85% of the foliage produced. Root stock grasses, such as *Calamagrostis rubescens* of the Pacific Northwest or tobosa in the Southwest, can withstand continued close grazing better and whenever possible types in which they predominate should be used during the early growing period, when it happens these two species are of most value. Black grama which predominates on large areas of the Southwest grows mainly on loose sandy soils and can be easily overgrazed in the summer. It cures well on the stalk and is especially valuable for winter and spring grazing. In early July, when new growth is about to start, the previous year's growth should not be grazed closer than when an average of about 2 inches of stem and basal leaf growth will remain on the tufts.

McGinnies found that to maintain the vigor of blue bunchgrass and slender wheat grass, the two most valuable species on a range under study in Montana, they should not be utilized more than 60 or 70% of their foliage production by early summer or more than 80 or 85% at the close of the summer grazing period. He also found

that the higher the successional stage of the vegetation, the greater the value of the range for livestock grazing. Table 1 gives representative successional types designated by their most characteristic species. As the range becomes depleted it tends to take on the characteristics of a more arid type, and conversely, as it improves the rainfall is better retained and is more effective in feed production. The higher successional stages were characterized by greater density of stand, a higher percentage of grass in the stand, and greater grazing capacity.

TABLE 1.—*Productivity of successional types of range vegetation.*

| | Blue bunch-grass | Slender wheat grass | Porcupine grass | Rabbit bush |
|---|---|---|---|---|
| Density of vegetation, % soil covered | 60 to 80 | 40 to 60 | 30 to 50 | 20 to 40 |
| Grasses, % | 75 | 65 | 85 | 25 |
| Weeds, % | 20 | 25 | 10 | 50 |
| Browse, % | 5 | 10 | 5 | 25 |
| Palatable, % | 62 | 54 | 49 | 25 |
| Number of surface acres to feed one cow one month | 2 | 3 | 4 | 11 |

Much the same result has been obtained in Utah. The badly depleted and seriously eroding range supports a very thin stand, largely of annuals of the first weed stage of succession. Partial destruction of the cover or partial recovery is more or less characteristic of the second weed stage. The mixed grass and weed stage has a denser cover, more adequate root systems, and greatly reduced erosion. This successional stage, which supports several highly palatable grasses and other forage plants, is often more valuable for sheep grazing than the climax herbaceous type which is made up largely of several wheat grasses.

The more fundamental studies have given a basis for developing the systems of forage management to apply on the different ranges. The deferred and rotation system of grazing, for example, is now extensively applied on national forests. Simply stated, this method provides for reserving until after seed maturity about one-fourth or one-fifth of the entire area used by the herd. Then that area is grazed. The rotation part of it comes in through allowing a different area to be reserved for seeding every year. The result is that there is an increase in carrying capacity of the range, a chance for improvement if the range is depleted, and better growth of animals without any loss through non-use of feed. An experimental area on the Jornada Reserve which has been grazed under the deferred system is over four times as valuable as the outside range heavily grazed yearlong.

The research has clearly indicated that the satisfactory use of range forage offers the greatest possibilities for developing more efficient production, decreasing costs, and increasing profits in the range livestock business. Plans provide for development of the work on a regional basis to study the important problems of range management, including the relation of grazing to other uses of range

lands. It will be of particular importance in the future to strengthen the study of the fundamental phases of the problem. The more we have studied the problem, the more we have realized its immensity and complexity, and the many phases that will need fundamental work before the problem as a whole will be finally solved. The results of these fundamental investigations will be an invaluable guide in the applied research, especially the further perfection of systems of range management, the more exact determination of carrying capacity, and the perfection of livestock management on the range.

## DISCUSSION

To most eastern agronomists the work of the U. S. Forest Service on range research is of interest particularly in connection with the methods in use by the Forest Service for the measuring of grazing capacity. The Forest Service study of the taxonomy of western grasses is only of academic interest, because the western grasses are all bunchgrasses, entirely different in character and species from the sod-forming grasses of the East.

To a considerable extent, the methods in use by the Forest Service have been worked out independently of agronomists and through 20 years or more of experience. With practically no exceptions, the experimenters have been foresters, stockmen, botanists, and ecologists, with little or no training in the standard methods of agronomy. Strangely enough, the methods which they have devised are essentially the same as those which are coming to be adopted by eastern agronomists, most of whom have had no connection whatever with the Forest Service. This indicates that the methods of experimentation are probably sound.

The Forest Service method of measuring vegetation involves the following:

1. Mapped quadrats, 1 meter square, divided into 100 squares, 1 decimeter on a side. The vegetation within the quadrat is sketched accurately at recorded intervals, and the vegetation areas measured by pantographs or otherwise. Thus the percentage of increase or decrease of ground cover can be stated accurately.

2. List quadrats are employed from which periodic lists of the pasture flora are prepared, and the changes in the vegetation through a period of years recorded with precision.

3. A third type of quadrat, called the "clipped quadrat," measures the effect upon different species of clipping at pre-determined heights and intervals. The measurements are made with much exactness and painstaking care.

Supplementing the quadrats is the so-called "isolation transect," an ingenious scheme for determining the effect through a period of years of any combination of grazing and protection. All experiments are graphically recorded by means of precise photographs, taken from exactly the same distance and elevation from a certain spot on each quadrat.

The Forest Service makes much use of ecology in its investigations, perhaps to a greater extent than would be warranted in the East where there is greater uniformity in the plant associations found upon pasture lands. Nevertheless, the eastern pasture investigator should have a comprehensive working knowledge of ecology, and a sympathetic understanding of its possible application.—L. W. KEPHART, *Bureau of Plant Industry, U. S. Dept. of Agriculture.*

# 8. ANALYSIS OF SEEDING MIXTURES AND RESULTING STANDS IN IRRIGATED PASTURES OF NORTHERN COLORADO[1]

HERBERT C. HANSON[2]

## INTRODUCTION

The analysis of seeding mixtures and resulting stands in irrigated pastures has received little study in the western states. Seeding mixtures have been based largely on empirical methods, with little or no consideration of the number of seeds per pound or of the factors influencing the survival and competition of plants growing in the pasture. The purpose of this study, started in 1926, is to investigate these problems by more exact methods than have been used before. The results would be increased knowledge regarding the habits of pasture plants and the relations of different species to each other, to grazing, and to various kinds of cultural treatment. The data, secured by the application of more exact methods, should afford more reliable bases for making seed mixtures and for the management of pastures than the empirical methods now in use. More than 20 pastures have been studied and the results from 8 of these are presented in this paper.

The acreage of irrigated pasture land in northern Colorado has been increasing rather rapidly in the last few years. Most of the pastures are grazed by dairy cattle, others by sheep or beef cattle. The average assessed value of irrigated land in 1926 was $76.87 per acre. The grazing capacity is about one and one-half to two head of cattle per acre. No fertilizer, except manure on a few pastures, is used. The pastures are irrigated from two to six times during the season. On some farms the water supply may be scant or lacking during late summer.

## METHODS

The number of pounds of each kind of seed in the mixture does not appear to give a correct measure of the value of each constituent because of the great differences in size of seed between different species. For example, in a pound of brome grass seed there are about one-fourth as many seeds as in a pound of orchard grass and one-sixteenth as many as in a pound of Kentucky bluegrass. Furthermore, the percentages of germination and of purity differ considerably between species. In Kentucky bluegrass the percentages of germination and purity are about 80, but in meadow fescue the percentages are 95 and 99, respectively.

[1]Paper read as part of the symposium on "Pasture Management Research" presented at the joint session of the New England Section of the Society and Section O of the A. A. A. S. held in New York City, December 28, 1928.

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A better criterion for measuring the value of each species in the seed mixture, therefore, appeared to be the approximate number of seeds after subtracting the dead seeds and impurities. This number of pure live seeds of each constituent in the mixture was secured by multiplying the number of seeds in 1 pound by the percentage of germination by the percentage of purity by the number of pounds used. The ratio of pure live seeds between the different constituents in the seed mixture was then computed. This ratio in percentage as well as the number of pounds of each kind of seed are given in the tables for each mixture that was analyzed. Table 1 gives the data that were used in calculating the number of pure live seeds.

TABLE 1.—*Approximate number of seeds per pound, percentages of germination and purity, and number of pure live seeds per pound.*

| Kind of seed | Number of seeds per pound | Germination % | Purity % | Vigor of seedling |
|---|---|---|---|---|
| Kentucky bluegrass. | 2,177,000 | 80 | 80.0 | weak, due to small seed |
| Brome grass, smooth | 136,000 | 90 | 85.0 | very strong |
| Clover, white...... | 680,000 | 95* | 99.8 | strong |
| Clover, yellow sweet. | 258,500 | 95* | 99.5 | strong |
| Fescue, meadow.... | 226,800 | 95 | 99.0 | very strong |
| Orchard grass...... | 521,600 | 90 | 80.0 | very strong |
| Timothy.......... | 1,134,000 | 95 | 99.8 | weak due to small seed |
| Wheat grass, slender. | 149,700 | 90 | —— | strong |

*Includes hard seed.

The figures in the first column of Table 1 were compiled from data secured by the Association of Official Seed Analysts of America.[3] The data in the other columns were secured from the Colorado Seed Laboratory.

Quadrats, a meter square, were used to determine the stand in the pastures. From four to eight quadrats were carefully located in typical parts of pastures that were 6 to 12 acres in size. In the first fall following seeding, the individuals in each quadrat were counted according to species and the proportion of plants in each species in the total number of plants in the quadrat was calculated on a percentage basis. The figures for the several quadrats in each pasture were then averaged. After the first year it was impossible, usually, to count individual plants due to the spread of certain species by rhizomes, and also frequently, due to the density of stand.

The method employed was to divide the square meter into 25 squares. The total amount of soil covered by vegetation (density), as well as the proportion occupied by each species in each square, were estimated. Totals and averages for each quadrat were then calculated. This method will be described in greater detail and compared with other methods in a forthcoming paper.

## EXPERIMENTAL DATA

Data are presented from eight pastures located within a radius of 25 miles from Fort Collins. The soils varied from fine sandy loam

[3]ANONYMOUS. Rules for seed testing. U. S. D. A. Circ. 406. 1927.
MUNN, M. T. Rules for seed testing. N. Y. State Agr. Exp. Sta. Circ. 73. 1924.

to rather heavy clay. The seed mixtures varied considerably in the kind of species used and ranged from totals of 30 to 50 pounds of seed per acre. All of the pastures were on farms and subjected to regular farming conditions. Most of the pastures received good care but that given the Gettman and County Farm pastures was almost ideal.

NELSON PASTURE, 1927

In the spring of 1927, 12 acres were seeded by drilling to the mixture shown in Table 1. One peck of barley per acre was used as a nurse crop. About half of the land had a gentle slope, while the other half was almost level. The soil was a fine sandy loam. Two quadrats were located on the sloping part and two on the level part. The irrigation was ample. The barley was cut for grain. Grazing by sheep was permitted after August 20, but there appeared to be no overgrazing. The pasture received good care during the second season also. The results are given in Table 2.

TABLE 2.—*Seeding ratio and first and second year stands of pasture seeded in spring of 1927.*

| Plants | Seed per acre | | Stand, first year | | | Stand, second year (average density 35%) |
|---|---|---|---|---|---|---|
| | Pounds | Pure live seeds % | Mixture ratio % | Survival % | +weeds ratio % | % |
| Brome grass | 15 | 15 | 14 | 25 | 10 | 9.0 |
| Meadow fescue | 10 | 21 | 27 | 36 | 20 | 26.5 |
| Orchard grass | 15 | 55 | 47 | 23 | 35 | 62.9 |
| Yellow sweet clover | 4 | 9 | 12 | 34 | 9 | 0.0 |
| Weeds | — | — | — | — | 26 | 1.6 |
| Totals | 44 | 100 | 100 | — | 100 | 100.0 |

The average stand (omitting weeds) at the close of the first season was unusually close to the seeding ratio of 15, 21, 55, and 9, respectively. The survival percentage ranged from 23% for orchard grass to 36% for meadow fescue. When the weeds were considered in the stand the percentages showed a high proportion of weeds in view of the large amount of forage seed used and the effect of the nurse crop. The weeds and sweet clover made up higher proportions of the stand in the dry parts than in the moister parts of the pasture. The chief weeds were wild buckwheat (*Polygonum convolvulus*), lamb's quarters (*Chenopodium album*), and pigweed (*Amaranthus retroflexus*).

At the close of the second season, October 20, 1928, the pasture was in good condition. It had not been grazed too closely. The sweet clover plants were now mostly dead, but much seed had formed. Meadow fescue had produced much seed and seedlings were found. The different species of grasses appeared equally grazed. The density of the stand averaged 35%, varying from as low as 18% in the drier sloping part to as high as 52% in the level part. The quadrats established in 1927 were again listed. No sweet clover was listed because all the plants were dead. In comparing the 1928 ratio with that for 1927, the chief changes, aside from the sweet clover, were in the great decrease of weeds, from 26 to 2%, and the increase in orchard grass, from 35 to 63%.

This seed mixture, containing 55% of orchard grass, resulted in pasture vegetation that was chiefly orchard grass (63%) at the close of the second growing season. The large amount of yellow sweet clover that was seeded, 4 pounds per acre, resulted in a dense stand which probably tended to suppress the grasses somewhat. The weeds were greatly decreased the second season due to grazing by sheep and to the suppressing effect of the forage plants, especially sweet clover and orchard grass.

It appears advisable to reduce the amount of sweet clover seed in this mixture from 4 to 2 pounds per acre and to decrease the proportion of orchard grass, thus giving meadow fescue and brome a better chance to grow.

### NELSON PASTURE, 1924

Another pasture of about 12 acres was seeded on this farm in 1924 under conditions similar to those described for the preceding pasture, and has been used for sheep grazing. The mixture seeded and the stand in 1927 are shown in Table 3.

TABLE 3.—*Seeding ratio and stand in 1927 of pasture seeded in 1924 and grazed to sheep.*

| Plants | Seed per acre Pounds | Seed per acre Pure live seeds % | Stand, Aug. 6, 1927 Mixture ratio % | Stand, Aug. 6, 1927 Survival % | Stand, Aug. 6, 1927 +weeds ratio % |
|---|---|---|---|---|---|
| Brome grass | 15 | 9 | 5 | 2 | 5 |
| Meadow fescue | 10 | 13 | 20 | 6 | 18 |
| Orchard grass | 15 | 34 | 65 | 7 | 60 |
| Yellow sweet clover | 4 | 6 | 10 | 6 | 9 |
| Timothy | 6 | 38 | 0 | 0 | 0 |
| Weeds | — | — | — | — | 8 |
| Totals | 50 | 100 | 100 | — | 100 |

On August 6, 1927, due to close grazing, the pasturage was extremely short, about as close as the sheep could eat it. Orchard grass and meadow fescue leaves were mostly flat on the ground. On an area basis the percentage of these two in the stand would have been still higher. Only a small percentage of the seed planted in 1924 had survived.

In 1927, this pasture was composed of 3/5 orchard grass and about 1/5 meadow fescue. Due to the very close grazing in the summer and fall of 1927, these plants, especially the former, were greatly weakened. The loss by winterkilling was so great, orchard grass suffering most, that the pasture was worthless and was plowed up. If the stand had consisted of a higher proportion of brome grass, it may have survived because this grass withstood the winter best, even though it had fewer leaves per plant in the preceding fall. This suggests decreasing the proportion of orchard and increasing that of brome in the seed mixture. Timothy should be omitted.

### DAVIS PASTURE

About 9 acres that had been in sugar beets in 1927 were seeded in April, 1928, to the mixture shown in Table 4. Orchard grass, bluegrass, and yellow sweet clover were seeded in one direction; brome grass at right angles to this; and 65 pounds of barley per acre

as a nurse crop at an angle of about 45° to both of these. Barley was seeded deepest, brome at about ¾ to 1 inch, and the others more shallow.

TABLE 4.—*Seeding ratio and stand at close of first season on Davis pasture.*

| Plants | Seed per acre Pounds | Seed per acre Pure live seeds % | Stand October 20, 1928 % |
|---|---|---|---|
| Brome grass | 22 | 11.1 | 34.3 |
| Orchard grass | 12 | 21.9 | 57.3 |
| Kentucky bluegrass | 10 | 63.4 | 1.9 |
| Yellow sweet clover | 3 | 3.6 | 1.2 |
| Meadow fescue | — | — | 2.3 |
| Timothy | — | — | 0.3 |
| Weeds | — | — | 2.7 |
| Totals | 47 | 100.0 | 100.0 |

On October 20 the pasture was excellent. The barley had been cut for grain in the latter part of July. No grazing had been permitted. Quadrat analysis of the vegetation is summarized in Table 4. The proportion of brome was unusually good, due to careful drilling. The very low proportion of sweet clover and weeds was doubtless due to the suppressing action of the nurse crop. The average density, 19%, was probably lower than if no nurse crop had been used. If less orchard grass were desired in the vegetation, the amount of this seed in the mixture could be greatly reduced. This would give the other species more chance to grow.

On this farm another area was seeded in April, 1927, to 15 pounds of brome grass per acre. On September 27 of the same year an excellent stand had been secured and quadrat analysis showed a survival of 76%. The only especial care given this pasture was in the depth of drilling, at ¾ to 1 inch.

## COUNTY FARM PASTURE

About 12 acres were seeded to the mixture shown in Table 5 in April, 1928, on fine sandy loam soil. Most of the surface had a gentle slope. The west half was in winter rye pasture in 1927 and in alfalfa in 1926. The east half was in sugar beets in 1927. A good seedbed had been prepared, especially on the beet land. No nurse crop was used. The drilling was done in two directions at right angles to each other and the field was then harrowed in direction of first drilling. Very good care was given. Certain parts of this pasture were difficult to irrigate and became rather dry at times.

TABLE 5.—*Seeding ratio and stand at close of first season of County Farm pasture, seeded April 2, 1928.*

| Plants | Seed per acre Pounds | Seed per acre Pure live seeds % | Stand, Oct. 1, 1928 Mixture ratio % | Stand, Oct. 1, 1928 Survival % | Stand, Oct. 1, 1928 +weeds ratio % |
|---|---|---|---|---|---|
| Brome grass | 10 | 10.4 | 27 | 58 | 13.6 |
| Meadow fescue | 6 | 12.8 | 24 | 42 | 12.1 |
| Slender wheat grass | 5 | 6.8 | 25 | 85 | 12.4 |
| Kentucky bluegrass | 4 | 52.4 | 5 | 2 | 2.4 |
| Yellow sweet clover | 3 | 7.4 | 11 | 35 | 5.6 |
| White clover | 2 | 10.2 | 8 | 20 | 3.9 |
| Weeds | — | — | — | — | 50.0 |
| Totals | 30 | 100.0 | 100.0 | — | 100.0 |

On July 20 the pasture was mowed at a height of 4 to 6 inches to kill weeds. During the latter part of the summer eight head of dairy cattle were permitted to graze lightly. No injury resulted from this. The results of counts made October 1, 1928, upon eight carefully located quadrats are summarized in Table 5.

The density of the stand was lower than expected, averaging 14% with a variation from 9.7% on the drier parts to 17.5% on the moister areas. This rather low percentage was due, in part at least, to the shading effect of yellow sweet clover and weeds upon the grasses and partly to the dryness of the soil in parts of the pasture. A reduction from 3 to 2 pounds in the amount of yellow sweet clover in the seeding mixture may have helped to increase the percentage of stand. The very large proportion of weeds, 50% of the stand, suggests that the crop preceding the pasture should have been one requiring clean cultivation. There were fewer weeds on the beet portion of the pasture than on the winter rye part.

Dryness of soil also favored the weed percentage. On the moist areas on the beet land the weeds were only 25% of the stand. The survival of brome, meadow fescue, and especially slender wheat grass was good. Kentucky bluegrass was very low, 2%, caused partly by insufficient irrigation. Many of the seedlings of this grass that started to grow must have died, because on June 5 and on July 16 the proportion of this species in the total number was much higher than on October 1.

## GETTMAN PASTURE

Four acres were seeded to the mixture shown in Table 6 about March 1, 1928, on land that had been in sugar beets the year before. The seed was drilled in one direction without a nurse crop.

TABLE 6.—*Seeding ratio and stand at close of first season on Gettman pasture, seeded March 1, 1928.*

| Plants | Seeds per acre: Pounds | Seeds per acre: Pure live seeds % | Stand, Sept. 22, 1928 % |
|---|---|---|---|
| Brome grass | 10 | 17.9 | 17.9 |
| Meadow fescue | 6 | 21.9 | 18.3 |
| Slender wheat grass | 4 | 9.2 | 4.9 |
| Orchard grass | 4 | 25.8 | 52.8 |
| Yellow sweet clover | 6 | 25.2 | 4.3 |
| Weeds | — | — | 1.8 |
| Totals | 30 | 100.0 | 100.0 |

The pasture received excellent care. It was irrigated four times up to September 22. The south half was mowed once to kill weeds. Sheep were permitted to graze moderately, beginning the middle of July. The summary of the two quadrats that were listed on September 22 is shown in Table 6. The stand was very uniform and all species were about equally grazed.

The excellent stand, 29% density, was due to a number of factors, including a good seedbed, favorable conditions following seeding, timely irrigation, and judicious grazing. The high proportion of orchard grass, 53% of the total stand, was surprising in view of the fact that only 4 pounds of seed were used in the 30 pounds of the

mixture. The proportions of brome grass and meadow fescue were lower than desired, while the percentages of slender wheat grass and yellow sweet clover were lower than were expected, due perhaps, to poor seed or competition with other plants. The small number of weeds was due to previous treatment of land (in sugar beets in 1927), grazing by sheep, and good growth of grasses.

The stand ratio suggests increasing the proportion of brome and meadow fescue seed and decreasing that of orchard. Slender wheat grass may well be left out as it is not as palatable to sheep as the other grasses.

### HICE PASTURE

An area of about 5 acres, formerly in grain, was seeded to the mixture shown in Table 7 about April 1, 1927. The seed was drilled in one direction with a heavy nurse crop of 5 pecks of wheat per acre.

TABLE 7.—*Seeding ratio and first and second year stands of Hice pasture seeded in April, 1927.*

| Plants | Seed per acre: Pounds | Seed per acre: Pure live seeds % | Stand first year: Mixture ratio % | Stand first year: Survival % | Stand first year: +weeds ratio % | Stand second year % |
|---|---|---|---|---|---|---|
| Brome grass | 8 | 5 | 29 | 49 | 25 | 25.9 |
| Kentucky bluegrass | 5 | 40 | 10 | 2 | 9 | 0.6 |
| Meadow fescue | 8 | 10 | 47 | 39 | 41 | 51.8 |
| Timothy | 5 | 32 | 9 | 2 | 8 | 5.1 |
| White clover | 4 | 13 | 5 | 3 | 4 | 6.4 |
| Yellow sweet clover | — | — | — | — | 1 | 0.1 |
| Weeds | — | — | — | — | 12 | 10.1 |
| Totals | 30 | 100 | 100 | — | 100 | 100.0 |

An excellent crop of wheat was grown the first season and the pasture plants were greatly suppressed. The soil frequently became very dry and hard with large cracks in it. The pasture plants were neglected in favor of the grain crop. On September 6, 1927, five quadrats were listed. More brome grass survived than any other species, while meadow fescue was second. Although brome and meadow fescue formed only 5 and 10% respectively, in the seeding ratio, they made up 29 and 47%, respectively, of the stand on September 6.

During the second season, grazing by horses was light but very spotted. The care was not good as shown by dryness and hardness of the soil, deep cracks, and hoof marks caused by the slipping of the horses when the soil was wet. In spite of the poor treatment brome grass and white clover spread vegetatively and the clumps of meadow fescue enlarged. Seed was produced by these plants as well as by timothy. Fescue seedlings were rather numerous in more favorable spots. Barnyard grass (*Echinochloa crus-galli*) and black medic (*Medicago lupulina*) seeded profusely.

On September 18, 1928, the five quadrats established in 1927 were again listed. The results are summarized in Table 7. The average density of the vegetation was 21%. Meadow fescue formed the highest proportion of the stand, with brome second.

Since September 6, 1927, meadow fescue had increased its proportion from 41 to 52%, while brome remained about the same,

timothy and weeds decreased slightly, white clover increased slightly, and bluegrass decreased from 9 to less than 1%. The most abundant weeds were dandelion, fetid marigold (*Dysodia papposa*), sage (*Salvia lanceolata*), barnyard grass, and foxtail.

Due to lack of care (delay in removing nurse crop, insufficient water causing dry, hard, cracked soil, and trampling and slipping of horses in wet weather), the pasture was not as good as it should have been at the close of the second season. Under all the difficulties the stand secured was surprising. Meadow fescue and brome grass were the most successful. Weeds were more abundant at the close of the second season than is usual where better care is given. A better mixture for these conditions would have included orchard grass and yellow sweet clover with brome and meadow fescue, omitting timothy, bluegrass, and white clover. The invasion of black medic should help improve the pasture.

## WELTY PASTURE

This pasture, planted about 1899, is one of the oldest irrigated pastures in northern Colorado. It was seeded chiefly to Kentucky bluegrass and alsike clover, with some smooth brome, English and Italian rye, orchard, and meadow fescue. The pasture is usually irrigated but two times during the summer. Stock are on the pasture from about April until late fall. The grazing capacity is about two head of beef cattle per acre. The soil is a network of rhizomes, roots, and decaying stems and leaves for several inches below the surface. It has taken years to produce the large amount of humus in the soil.

On November 12, 1928, five list quadrats were established to determine the composition of the vegetation. On these quadrats the average density of the vegetation was 76%. Kentucky bluegrass formed by far the largest proportion of the vegetation, 80%, with white clover second with 13% (Table 8). In a rather low part of the pasture a few years ago there was considerable alkali due to seepage. There was much squirrel tail grass (*Hordeum jubatum*) on this spot. Tile drainage was put in and now the chief plant is false quack grass, but bluegrass and white clover are invading also.

The chief weed is dandelion. Others are squirrel tail grass, shepherd's purse, ragweed, and poverty weed (*Franseria tomentosa*).

TABLE 8.—*Percentage of each species on November 12, 1928, in each of five quadrats and in the average composition of the vegetation on Welty pasture, seeded about 1899.*

| Plants | Quadrats 1 % | 2 % | 3 % | 4 % | 5 % | Average % |
|---|---|---|---|---|---|---|
| Kentucky bluegrass | 69.0 | 79.2 | 80.8 | 87.4 | 83.6 | 80.0 |
| False quack grass | 0.2 | 7.6 | 0.2 | 0.0 | 6.0 | 2.8 |
| White clover | 26.0 | 9.3 | 17.1 | 8.3 | 4.5 | 13.0 |
| Brome grass | 0.0 | 2.2 | 0.6 | 0.4 | 0.5 | 0.8 |
| Orchard grass | 0.0 | 0.3 | 0.1 | 3.3 | 4.5 | 1.6 |
| Weeds (especially dandelion) | 4.8 | 1.4 | 1.2 | 0.6 | 0.9 | 1.8 |
| Totals | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |

In addition to the tame forage species listed in the quadrats, there are a few other species found very sparingly over the pasture. These are timothy, red clover, and alsike clover.

## CONCLUSIONS

Analysis of the seeding mixture into percentages of pure live seeds and knowledge of the habits of seedlings aid greatly in explaining resulting stands. For example, a seed mixture (Nelson pasture, 1927) was used that contained 15 pounds of brome grass seed, 10 of meadow fescue, 15 of orchard grass, and 4 of yellow sweet clover per acre. At the close of the second season the stand consisted of 9% brome grass, 26% meadow fescue, 63% orchard grass, and 2% weeds. The high proportion of orchard grass is explained partly by the pure live seed ratio in which orchard grass made up 55%; brome 15%; meadow fescue, 21%; and yellow sweet clover, 9%. The vigor of the seedlings and their early production of tillers also help to explain the dominance of orchard grass in the stand even when much smaller amounts of seed are used, as in the Gettman pasture where only 4 pounds (26% pure live seed) were used in a total of 30 pounds per acre.

In order to secure a well-balanced seedmixture, it appears that the pure live seed ratio and the vigor and habits of the seedlings must be taken into consideration in order to secure the kind of pasturage that is desired. If a large proportion of brome grass is desired in the pasture, then the amount of pure live orchard grass seed should be less than that of brome grass. Yellow sweet clover when planted at the rate of 3 or more pounds per acre exerts a suppressing effect upon some of the grasses. As good stands were secured with 30 pounds of seed per acre as with 50 pounds.

Other factors to be considered in growing the kind of pasturage that is desired in addition to the seed mixture are treatment of the land before seeding the nurse crop, care of pasture, effects of grazing by various classes of stock, grazing capacity throughout the season, and competition and succession of pasture plants with each other and with weeds. The number of weeds in a pasture are greatly affected by the kind of crop grown on the land preceding the pasture. When a clean cultivated crop, such as sugar beets, preceded the pasture, as on the County Farm, then the weeds are much less numerous than when rye was grown for temporary pasturage. Sugar beets make an excellent crop to precede the pasture for the additional reason that they facilitate the preparation of a good seedbed.

The Hice pasture did not receive adequate care. The nurse crop received more attention than did the pasture plants, and hence an excellent crop of wheat was secured but a very poor stand of pasture plants. The latter suffered further from inadequate irrigation and poor grazing methods. The seed mixture that was planted was not at all adapted to such treatment. On other pastures that were studied the nurse crop did decrease the weed percentage but may have injured the growth of seedling forage plants. The weed problem was handled very nicely on the County Farm and Gettman pastures by mowing and carefully regulated grazing, with probably less damage to the growth of the seeded species than if a nurse crop had

been used. Overgrazing or highly selective grazing affects the composition of the pasture. Overgrazing by sheep on the Nelson, 1924, pasture in the late summer and fall of 1927 resulted in the death by winterkilling the following winter of most of the orchard grass. Brome grass and meadow fescue were only slightly affected. Since the vegetation in the pasture consisted of at least 60% orchard grass, there were very few live plants the following spring and the pasture was ruined. A higher proportion of brome grass and meadow fescue would have enabled the pasture to survive far better.

In deciding upon a pasture mixture the class of stock for which it is intended needs consideration. Slender wheat grass could well have been left out of the Gettman pasture because sheep do not graze this grass as well as others when it becomes older. Orchard grass is much less palatable to both cattle and sheep when it approaches the blooming period, than when it is younger, but brome grass does not lose so much in palatability. Kentucky bluegrass, brome grass, and white clover are especially palatable to both sheep and cattle.

The grazing capacity throughout the season is another factor that should be considered in deciding upon the seed mixture. If sufficient irrigation water is available, as on the Welty pasture, Kentucky bluegrass and white clover produced most of the forage from early May to November, supporting about two head of beef cattle per acre. If irrigation water is scant in the latter part of the summer, brome grass, meadow fescue, and yellow sweet clover produce better than the other two species.

Competition and succession play an important part in all the pastures. The most vigorous seedlings (see Table 1), especially orchard grass, soon gain the dominance even when seeded in as small amounts as 4 pounds per acre in a total of 30 pounds. Kentucky bluegrass, white clover, and timothy suffer greatly in competition with them. If much orchard grass seed is used, seed of these weaker plants is mostly wasted if used in the same mixture. Much of the seed of even brome grass and meadow fescue is also wasted due to the inability of the seedlings to compete with orchard grass or with sweet clover if much of the latter is seeded. The process of competition is complicated by soil and climatic conditions, care given the pasture, nurse crop, class of stock, and degree of grazing.

The most vigorous species, such as orchard grass and sweet clover will dominate the pasture the first few years after seeding. Sweet clover may be greatly reduced or disappear at the close of the second season unless reseeded. The course of succession depends in a very large measure upon the factors mentioned in the preceding paragraph as well as to seeds brought in by irrigation water, but examination of the Welty and other old pastures in northern Colorado shows that their composition is chiefly Kentucky bluegrass and white clover. Dandelion and black medic are also abundant, but brome grass, orchard grass, meadow fescue, timothy, sweet clover, and others are much less abundant. These older pastures were seeded to a variety of mixtures. The investigation of seeding mixtures, resulting stands, and factors affecting both mixtures and stands is being continued.

# 9. THE ERADICATION OF BRUSH AND WEEDS FROM PASTURE LANDS[1]

A. E. ALDOUS[2]

Kansas contains approximately 22 million acres of land used for pasture. Most of this land is potentially valuable only for grazing livestock, owing to the broken character of the surface or the shallow nature of the soil which make cultivation impractical. A study of statistics has shown that the grazing value of this land has greatly decreased in the last 25 years. In the Flint Hill region, which occupies about 5 million acres of some of the best pasture land in the United States, this decrease has been approximately 25%. Such reduction has been accompanied in most instances by an incoming of worthless plants that have taken the space formerly occupied by the valuable grasses. This change has been most pronounced on small farm pastures where improper grazing methods have been more generally practiced.

The eradication of the non-palatable vegetation is an important factor in the restoration of the pastures to their normal productivity. The eradication work should also be accompanied by such grazing methods as will permit the forage plants to come back. In view of the great need for information on the improvement of run-down pastures, experiments were started in 1926 by the Kansas Agricultural Experiment Station to determine the best methods of eradicating weeds and brush. The report on the results presented in this paper are only preliminary, owing to the short time that the experiments have been conducted. It is also impossible to report on most of the work done during the past summer because the results cannot be checked until growth starts next season.

## ERADICATION METHODS

In conducting the experiments, three general eradication methods were used, *viz.*, (1) spraying with chemicals and herbicides, (2) burning, and (3) cutting. In the first method, two concentrations of sodium chlorate, which has been so successfully used in the eradication of bindweed, sodium arsenate, and zinc chloride were applied by spraying on sumac (*Rhus glabra*).

### RESULTS FROM USE OF HERBICIDES

The results of one season's work show that two applications of sodium chlorate, applied at the rate of 100 pounds per acre, killed 78% of the sumac stems. This treatment was also found to be very detrimental to the forage species, reducing the stand about one-half. Where the sodium chlorate was applied at the rate of 50 pounds per acre, two applications killed about 25% of the stems. This solution had little effect on the forage plants.

[1]Contribution No. 179, Dept. of Agronomy, Kansas Agricultural Experiment Station, Manhattan, Kan. Paper read as part of the symposium on "Pasture Management Research" presented at the joint sessions of the New England Section of the Society and Section O of the A. A. A. S. held in New York City, December 28, 1928.

[2]Agronomist.

Two sprayings of a 2% solution of sopium arsenate was only about 10% effective in killing sumac, but it had little detrimental effect on the grasses. A 1% solution did not have any noticeable effect on the sumac or the forage plants.

Zinc chloride applied at the rate of 100 pounds per acre was not over 5% effective in killing sumac. It also had little effect on the grasses.

The limited work done with herbicides indicates that they are not practical to use in eradicating undersirable plants from pastures because the ones that are most effective in killing weeds and brush have an equally detrimental effect on the desirable species of vegetation. The cost of these treatments is also too great to have practical application. In addition, some of the chemicals, particularly sodium arsenate, are very poisonous and their use would involve risk of losses unless all the stock were removed from the pasture.

## BURNING

Burning pastures is generally practiced through the prairie grass region of Kansas. It is done primarily to stimulate early growth in the spring, to obtain more uniform grazing over the pasture, and to control weeds and brush. These investigations conducted over two years indicate that burning can be effectively used in controlling weeds and brush, but the burning has to be done late in the season, about May 1 or later in the vicinity of Manhattan, to be very effective. The main difficulty encountered in the use of this system on extremely weedy or brushy pasture lands is that these areas do not usually produce sufficient dry material to make enough fire to kill the weeds and brush. The effective use of burning often necessitates the protection of such areas for at least one season.

Table 1 shows the effect of burning at different times during the spring in controlling weeds for the years 1927 and 1928.

TABLE 1.—*Value of burning over pastures as a means of controlling weeds.*

| Time of burning | Dry weight of weeds in pounds per acre | | |
|---|---|---|---|
| | 1927 | 1928 | Average |
| Check | 548 | 299 | 424— |
| Early spring burned (March 15) | 411 | 460 | 435+ |
| Medium spring burned (April 15) | 870 | 430 | 650 |
| Late spring burned (May 10) | 64 | 3 | 34— |

These plats had been protected from grazing since 1920 and had been burned during 1921 and 1922 as well as during the last two seasons. As will be noted from these figures, the late spring burning killed nearly all the weeds. The burning at earlier dates does not appear to be very effective. The amount of weeds in the more weedy plats is not in excess of what will be found on most stands of prairie grass.

## EFFECT OF BURNING ON BRUSH

Table 2 gives the data on the effect of burning on buck-brush (*Symphicarpos vulgaris*). These plats were burned in 1927 and 1928.

TABLE 2.—*Eradication of buck-brush by burning.*

| Time of burning | Number of stems before original burning | Number of stems Oct. 27, 1927 | Average height of stems, inches | Number of stems Oct. 27, 1928 | Average height of stems, inches |
|---|---|---|---|---|---|
| April 15... | 480 | 1,607 | 20 | 1,075 | 13 |
| May 10.... | 164 | 84 | 8 | 42 | 6 |
| Check..... | 320 | 334 | 36 | 342 | 36 |

These plats were selected in dense stands of buck-brush that contained a very scattering growth of grass. They had been protected from grazing since 1921, although none of the plats had been burned prior to 1927. An examination of the plats in October, 1928, showed that the late burning had completely killed all the buck-brush. On the earlier burned plats, the vigor of the stems has been very much reduced even though the number has been greatly increased. It is believed that continued burning at this time would decrease the vigor of the plants until eventually they would all be killed.

The effect of burning on the organic reserves in the roots of buck-brush is shown by the chemical analysis (Table 3) made from samples of roots collected in October, 1927.

TABLE 3.—*Organic reserves in buck-brush roots from burned and unburned areas.*

| Source of roots | Protein % | Total invert sugars % | Starch % | Ash % | Crude fiber % |
|---|---|---|---|---|---|
| Unburned plat....... | 4.00 | 2.26 | 27.00 | 5.32 | 45.85 |
| Burned plat.......... | 3.12 | 2.71 | 21.50 | 5.92 | 48.51 |

The analysis shows the amount of starch, in which form a large percentage of the organic reserves is stored, to be very materially less in the late burned plats.

The experimental data suggest that late burning is very effective in controlling both weeds and brush in prairie grass pastures. Its use is not advisable on short grass, grama or buffalo sod, or on tame pastures, owing to the damage that is done to these forage species. Kentucky bluegrass is especially sensitive to burning. From the investigation conducted thus far, no great damage can be detected from this treatment to prairie grasses where big and little bluestems (*Andropogon furcatus* and *A. scoparius*) are the dominant species. Late burning, however, appears to favor the growth of big bluestem at the expense of little bluestem. The quantity of air-dry vegetation on burned plats has been greater than on any of the other treated plats almost equalling the amount produced on the check plats. The green weight was higher than on the check plat. The method also involves little expense which is an important factor in weed control on pasture lands. In prairie grass regions, where burning is usually practiced, it is believed that weeds and brush can be effectively controlled on most pastures by this method.

## CONTROL OF WEEDS AND BRUSH BY CUTTING

The work in cutting sumac and buck-brush was started in August, 1926. Plats were cut at two-week intervals during the remainder of the growing season of 1926 and also during the seasons of 1927 and 1928. When the cuttings were made, the number and height of

stems growing on the plats were recorded. Samples were also taken of the roots and stems for microscopic examination of the starch content to determine whether the quantity of starch in the plants at different stages of growth is a measure of their vigor and resistance to any method of eradication used.

Table 4 gives the data on the effectiveness of cutting buck-brush. The stems were cut above ground. Plats 1 to 11 were cut twice since the original cutting was made. The second cutting was made September 13, 1927, and the third, June 14, 1928. Plats 12 to 15 have been re-cut only once, June 14, 1928.

TABLE 4.—*The eradication of buck-brush by cutting.*

| Plat No. | Date of first cutting | Number of stems first cutting | Number of stems removed by re-cuttings | Maximum height of stems last cutting June 14, 1928, inches | Increase or decrease in number of stems from original number | Percentage effectiveness of cutting on plats having decreased number of stems |
|---|---|---|---|---|---|---|
| 1 | Aug. 10, '26 | 80 | 313 | 24 | +233 | — |
| 2 | Aug. 24, '26 | 112 | 187 | 22 | + 76 | — |
| 3 | Sept. 8, '26 | 132 | 222 | 18 | + 90 | — |
| 4 | Sept. 22, '26 | 140 | 211 | 16 | + 71 | — |
| 5 | Oct. 5, '26 | 185 | 307 | 21 | +122 | — |
| 6 | Apr. 27, '27 | 127 | 156 | 22 | + 29 | — |
| 7 | May 10, '27 | 218 | 34 | 12 | —191 | 87 |
| 8 | May 25, '27 | 369 | 176 | 10 | —193 | 53 |
| 9 | June 9, '27 | 138 | 129 | 10 | — 32 | 24 |
| 10 | June 22, '27 | 144 | 172 | 17 | + 38 | — |
| 11 | July 6, '27 | 265 | 309 | 20 | + 48 | — |
| 12 | July 18, '27 | 218 | 210 | 21 | — 8 | — |
| 13 | Aug. 1, '27 | 143 | 150 | 24 | + 7 | — |
| 14 | Aug. 15, '27 | 104 | 115 | 19 | + 11 | — |
| 15 | Aug. 22, '27 | 260 | 354 | 34 | + 94 | — |

A careful examination of these plats last October showed that all the plants had been killed on plat 7, while there were 17 stems on

TABLE 5.—*The eradication of sumac by cutting.*

| Plat No. | Date of first cutting | Number of stems first cutting | Number of stems removed from plats by re-cuttings | Maximum height of stems last cutting June 13, 1928, inches | Increase or decrease in number of stems from original number on plats | Percentage effectiveness of cutting on plats having decreased number of stems |
|---|---|---|---|---|---|---|
| 1 | Aug. 10, '26 | 40 | 114 | 20 | +74 | — |
| 2 | Aug. 24, '26 | 36 | 95 | 18 | +59 | — |
| 3 | Sept. 8, '26 | 25 | 66 | 15 | +41 | — |
| 4 | Sept. 22, '26 | 40 | 99 | 14 | +59 | — |
| 5 | Oct. 5, '26 | 33 | 77 | 16 | +44 | — |
| 6 | Apr. 27, '27 | 21 | 66 | 16 | +45 | — |
| 7 | May 10, '27 | 86 | 134 | 19 | +48 | — |
| 8 | May 25, '27 | 75 | 41 | 19 | —34 | 45 |
| 9 | June 8, '27 | 61 | 23 | 12 | —37 | 60 |
| 10 | June 22, '27 | 73 | 49 | 12 | —24 | 33 |
| 11 | July 6, '27 | 94 | 66 | 15 | —28 | 30 |
| 12 | July 18, '27 | 116 | 93 | 19 | —23 | 19 |
| 13 | Aug. 1, '27 | 140 | 143 | 24 | + 3 | — |
| 14 | Aug. 15, '27 | 109 | 140 | 23 | + 31 | — |

plat 8 and 11 on plat 9. The grass has practically replaced the buck-brush on these plats. This shows that the eradication of buck-brush was accomplished in three cuttings on plat 7 originally cut May 10. On this plat less than 20% of the original number of plants made new growth. The decreased number of stems on plats 12, 13, and 14 is due to the fact that they were re-cut only once. A re-count on these plats in the early summer will undoubtedly show the effectiveness of cutting to be less than on plat 11.

Before going into the apparent reasons for the greater effectiveness of the cutting in the early part of May, the data on cutting sumac is presented in Table 5.

Plats 1 to 9 have been cut three times. The second cutting was made September 10, 1927, and the third, June 13, 1928. The other five plats were re-cut only once, the last cutting having been made June 13, 1928.

An examination of the plats last October showed three small stunted stems on plat 9 and a few on plats 8, 10, and 11. A definite determination of the effectiveness of cutting will not be possible until after growth starts next spring. The data indicate, however, that two cuttings have almost completely eradicated the sumac on plat 9 cut June 8, and that less than one-half the original number of stems on the plat grew after the original cutting. The effectiveness of the cuttings also appear, in a general way, to decrease as the cuttings are made earlier or later than this date.

As previously stated, samples of roots and stems were collected for both the sumac and buck-brush at the time each plat was originally cut. A microscopic examination of stained sections cut from the roots and stems of sumac and buck-brush showed a relation between the effectiveness of cutting and the starch content of the shrubs, particularly in the stems. In the buck-brush, the starch had practically disappeared in the cutting made May 10 when the cuttings were most effective. In the sumac, the least amount of starch in the stems was found June 10 at the time when the least number of new stems appeared after cutting. The starch content in the buck-brush was gradually restored in May and very rapidly in June, so that by the middle of July the stems appear to have as much starch as was found in them before growth started in the spring. The sumac restored its starch a little slower but by August the stems appeared to have restored the maximum amount.

Fig. 1 shows cross-sections of sumac and buck-brush stained with iodine to show the starch grains and indicates the quantities of starch found in these plants at different stages of growth. The amount of starch in the stems of these shrubs at these stages of growth is indicative of their vigor and resistance to any form of eradication that may be used.

The work done thus far on starch content indicates that the plants have the least amount of starch about the time they are in flower, and it is believed that this can be used as an indicator as to the most effective time to eradicate these two shrubs by mowing. This stage of development will vary in different years, according to seasonal

conditions, and in different sections, depending on latitude and altitude. The work that has been done with weeds also suggests that the quantity of starch found in these plants at different stages of growth is an indicator of their resistance to eradication methods.

With respect to the practical application of cutting on pasture lands, it has been found that a mowing machine can be used on most pastures for cutting buck-brush as the stems ordinarily do not grow large enough to prevent cutting. These shrubs are also most generally found on relatively smooth land where no difficulty is encountered in using a mowing machine. No difficulty will be encountered in mowing if the cutter bar is reduced in length to about 3½ feet. An old mowing machine can be used for this purpose.

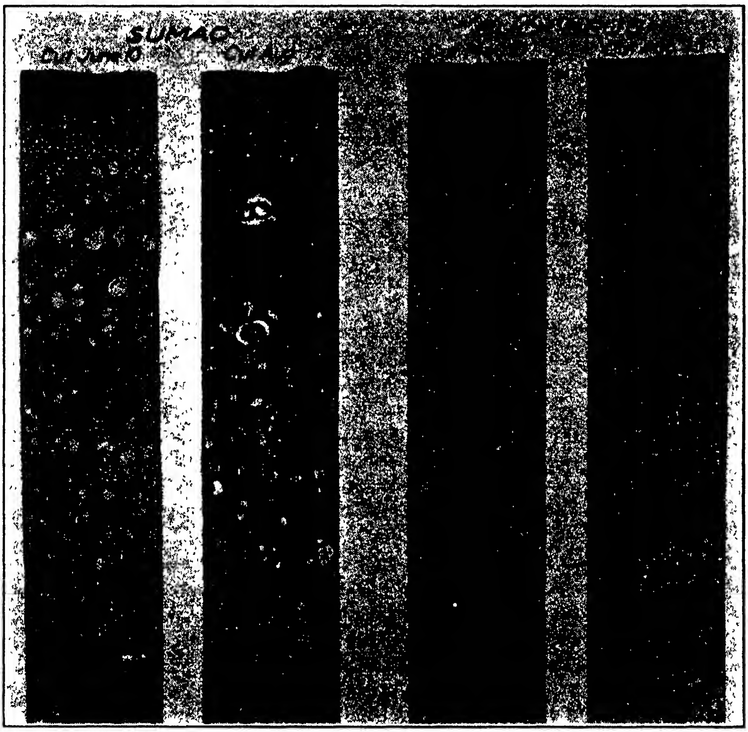


FIG. 1.—Cross-sections of sumac and buck-brush stems stained withi odine to show the starch content at different stages of growth.

Sumac, however, usually makes a much ranker growth, having thicker stems that are much harder to cut, making it necessary in heavier stands to use an ax or brush-hook for the first cutting. All subsequent cuttings can be easily made with a mowing machine.

The work has not progressed far enough to obtain figures on the cost of mowing these two shrubs, but it is not believed that the cost will be prohibitive considering the benefis obtained.

## DISCUSSION

The eradication of weeds and brush from pasture lands has received attention from agriculturists for a long time. In 1557, Thomas Tusser in his "Five Hundred Pointes of Good Husbandrie" says regarding the eradication of the bracken fern from pastures, "In June and in August, as well doth appeere, Is best to mowe Brakes of all times of the Yerre."

Aldous has emphasized that late burning, after May 10 or later, was very effective in controlling both weeds and brush in prairie grassland dominated by bluestems. Under these conditions *Andropogon furcatus* appeared to be favored at the expense of *A. scoparius*. If the latter is more palatable, there would be some loss in the value of the pasture due to burning. In northern Colorado it has been found that sagebrush range can be burned over in the fall with great success. The yield of grass the season following burning is increased many fold.

The best time to eradicate buck-brush, and sumac by cutting appears to be while they are in flower, about May 10 for the former and June 8 for the latter. Cox states (U. S. D. A. Farmers' Bul. 687) that the best times to eradicate (by cutting) ferns from pasture lands in southern New York are just before sporing, about the middle of June, and in the middle of August. These data are very important because they indicate the way to get rid of undesirable plants with least labor.

As the experimental work proceeds, it will be interesting to learn about the final effectiveness of the various methods, the relation of the age of sumac to starch content and cutting, effect of cutting and burning upon the rhizomes of both species, and the rate of invasion by seeds and rhizomes from plants just outside the plats or pastures.—HERBERT C. HANSON, *Colorado Agricultural College.*

## 10. METHODS OF RESEARCH IN PASTURE INVESTIGATIONS[1]

GEORGE L. SCHUSTER[2]

During the last decade the pastures of the United States have been receiving considerable attention from agronomists. Pasture investigations reported upon prior to this date were very meager or nil. This may be attributed to three factors, *viz.*, (a) the presence of abundant range and woodland pasture, (b) the soil was sufficiently fertile to produce a good rotation pasture, and (c) the expense of instituting a pasture project seemed prohibitive. The agronomist and the farmer have been giving most of their attention to the economic production of cash crops.

Pasture investigations are difficult to conduct because of the many variable factors that are difficult or impossible to control that may enter into any system of measurement of the results. Only permanent pasture of the eastern United States will be considered here in discussing these factors and methods of research.

The question arises as to how the results of any pasture investigation can best be measured and recorded. The results in general should point toward one general conclusion, i. e., longevity and carrying capacity of the meadow. A survey of the literature and of the pasture projects under way[3] indicates that there are 13 methods

[1]Paper read as part of the symposium on "Pasture Management Research" at the joint session of the New England Section of the Society and Section O of the A. A. A. S. held in New York City, December 28, 1928.

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[3]The author is indebted to Dr. A. J. Pieters of the U. S. Dept. of Agriculture for valuable assistance in securing these data.

of measurement in use in the eastern United States. These methods and their frequency of use are given in Table 1. This table is based upon the investigations that have been conducted or are being inaugurated in 12 states and by the U. S. Dept. of Agriculture.

TABLE 1.—*Methods of research employed by 12 states and by the U. S. Dept. of Agriculture in pasture investigations.*

| Methods | Number of places employed | Methods | Number of places employed |
|---|---|---|---|
| Profit | 2 | Surveys | 3 |
| Hay weights | 3 | Carrying capacity | 7 |
| Clippings | 6 | Milk flow | 3 |
| Cattle weights | 4 | Plant population | 5 |
| Sheep weights | 1 | Chemical analysis | 2 |
| Photographs | 4 | Palatability | 2 |
| | | Duration of grasses | 2 |

There are two states employing only one method; four employing two methods; two employing three methods; two employing four methods; and one state each, including the U. S. Dept. of Agriculture, employing five, six, and nine of the methods, respectively.

## METHODS EMPLOYED

### HAY WEIGHTS AND CLIPPINGS

Hay weights are annual cuttings of the meadow under ungrazed conditions, and as such, they represent the growth and production of meadows for hay and not for pasture.

Stapledon (4)[4] reports that in working with a pasture mixture the yield of hay and aftermath and the yield of hay pre-cut 11 times (pasture cuts) is in the same relative proportion as 100 is to 37.5. He also reports the relative number of tillers per plant to be as 100 is to 50.6, and the weight of roots per plant to be as 100 is to 38.6.

Granting that pre-cutting a pasture 11 times is equivalent to grazing conditions, it would seem that hay weights taken once a season are not equivalent to production under grazing conditions.

Further study of Stapledon's (4) results reveals the following data:

| | Hay after hay | Hay after pasture cuts | Hay after sheep |
|---|---|---|---|
| Relative yield of hay | 100 | 79 | 86 |
| Relative tiller production | 100 | 75 | 87 |

It is to be noted that the intermittent effect upon yield of grazing by sheep is not so great as where the hay is cut monthly by a mowing machine. Stapledon attributes this to the more severe defoliation caused by the mowing machine and the influence of the manurial residues resulting from the sheep grazing. The above results are weights taken from one cutting after a pre-treatment of grazing or several cuttings. The total yield of dry matter produced per season under various treatments is important.

Wiggans (7) shows that the growth of Kentucky bluegrass during the second half of the season was 44% of that produced during the

[4]Reference by number is to "Literature Cited," p. 672.

spring and early summer. He also shows an increase of 13% in the total yield of bluegrass when cut five times per season instead of only once. Other grasses yielded approximately one-half as much under repeated cuttings as when cut once.

Stapledon, et al (5), working at the Welsh Plant Breeding Station, obtained the following results with Italian rye grass:

| Number of cuts | Month of cut | Yield in dry matter per acre, pounds | Increase over one cutting % |
|---|---|---|---|
| 1 | March | 1,012 | |
| 2 | Sept. and March | 2,200 | 117.3 |
| 3 | Oct., Dec., March | 2,355 | 132.7 |
| 7 | Monthly, Sept. to March | 3,521 | 257.8 |

He says these results are opposite to those previously obtained with perennial grasses and attributed them partly to the fact that Italian rye grass recovers very quickly after cutting or grazing.

All of these data indicate that (a) hay weights are not satisfactory for the measurement of pasture production and (b) that if clippings are used to imitate grazing conditions several clippings (four or more per season) should be made. It should be remembered, however, that Stapledon has pointed out that under their conditions sheep grazing is not as severe on tiller production and total yield as pasture cuttings. Animals grazing upon a meadow have a different effect upon the meadow than frequent cuttings.

At the Delaware Station[5] square rod areas were fenced in on previously pasture-treated plats. These were harvested twice a season, first when the majority of the grasses were in the proper stage for hay and second about two weeks before the close of the season. These fenced areas were moved every season to an area that was grazed the preceding season, thus attempting to approach pasture grazing conditions. This scheme was continued for four seasons. Sixteen determinations were made in the spring and again in the fall of each season. It was found that the fall weighings were 66% of the spring weighings.

It is the opinion of the author that if these pens had been moved to a grazed area after the spring harvest still more accurate data under grazing conditions could have been obtained. Some of the experiment stations[6] are resorting to cages for this purpose. The cage method would permit of more replications and greater ease of moving to grazed areas several times per season, and would thus reduce the errors of soil variation and random sampling of the grazed areas.

Wood and Stratton (8) state that the probable error of field experiments is about 5% of the crop. This error is independent of the size of the plat, provided it is 1/80 acre or larger. With a probable error of 5% they show that it is useless to try to measure differences less than about 20% by comparing single plats; while duplicate plats will measure 15%, 4 plats 10%, and 10 plats 6%. Tables for other values are given.

[5]Unpublished data.
[6]Unpublished data.

It appears, therefore, that in arranging plats for pasture experiments some kind of replications should be provided for if a precision of less than 20% is desired.

### CATTLE WEIGHTS

Where cattle weights are used as a criterion for measurement it must be remembered that they are subject to considerable variation. The breed, age, size, hereditary complex, physiological makeup, sex, and stage of pregnancy must all be considered in selecting cattle for measuring pasture experiments. Wood and Stratton (8) state that the probable error of one animal (cattle and sheep) on a fattening ration is found to be about 14% of the live weight increase produced. From this it is calculated that to obtain a precision of 10% in an ordinary feeding experiment 29 animals must be fed on each ration. The probable error may not be the same for animals grazing and this factor should be determined before beginning the experiment if cattle weights are to be used.

Lush (2), in speaking of the accuracy of cattle weights, says that cattle weighed to the nearest 5 pounds sacrifices a considerable amount of information. Weighing to the nearest 2 pounds does not lead to any serious loss of information, except with really small cattle. Weighing to the nearest pound adds some accuracy when working with calves and small yearlings.

The relative error of a 1-day weight and a 3-day weight is as the square root of 1 and the square root of 1 /3 when the comparison is being made between the weight changes made by the experimental lot and the weight changes made by the control lot. However, if the experimenter wishes to study absolute changes in weight, as where there is no control lot, or to compare gains made at different times or in different places, the 3-day weight has the additional advantage of permitting the estimation of the day-to-day fluctuation in weights, and hence a more accurate estimation of the absolute weights and gains. For purposes of comparison with the control lot, weighing for two additional days eliminates about 42% of the error contained in a 1-day weight. If it is inconvenient or impossible to weigh more than 1 day, 3-day accuracy for comparison with the control lot may be attained by using three times as many animals in each lot. This procedure has the statistical advantage of giving a much smaller error of sampling, but economic reasons usually preclude its use.

Lush further states that the exprimental error in the accuracy of single weights may be expected to be between 6 and 12 pounds. The error is somewhat smaller with young cattle and is distinctly smaller under uniform environmental conditions. Age and capacity of the animal influences the experimental error more than the gross weight of the cattle.

### SHEEP WEIGHTS

The utilization of sheep in pasture experiments will permit the use of a larger number of animals and will thereby reduce the error of random sampling. However, the data obtained are not readily applicable to cattle grazing. The tramping effect and grazing habits of the two animals are entirely different and produce a different effect upon the pasture.

## PHOTOGRAPHS

A pictorial record of pasture is valuable provided it can be supported by other records. Photographs are valuable for striking differences, such as weed population, but they are not so good for showing turf formation and plant population under grazing conditions. No measure of the growth of grasses under grazing conditions can be shown by photographs. This was tried at the Delaware Station. The ratings for various grass mixtures and fertilizer treatments under grazing conditions were made from observations and clippings. Photographs were also taken. Several individuals were asked to place these photographs according to what they thought were the best pastures. Most of them placed the three highest ones in each group but were unable to agree as to a placing of the three as 1st, 2nd, 3rd, or to agree with the records taken. Photographs may be used as an aid, but should not be used for the entire record.

## SURVEYS

A survey of the pasture situation in a given district is valuable. The conditions and pasture problems are observed and the best practices are revealed. If the best practices for pasture production are all that needs to be recommended, then the problem is solved; but if further improvements are deemed advisable, extensive research is necessary. A pasture survey orients the problem for the district in which it has been made.

## CARRYING CAPACITY

The largest number of projects are being measured by this method. Just what is meant by carrying capacity? Does it mean carrying so many cattle per acre and gaining in weight, holding their weight, or are they fed a concentrated ration in addition? If the average carrying capacity of grass lands in a given district is 4 to 5 acres per cow and by certain treatments it is increased to 1 acre per cow, one has a definite measure; but under which of the three methods given above was it obtained? Also, has the maximum capacity been reached?

In testing the carrying capacity of a meadow there is usually provided another meadow in which the cattle graze when the meadow under observation gets too low. Will the results be the same as if there had been a smaller number of cattle on the meadow under test for the entire season?

Carrying capacity tests should be conducted for a number of seasons in order to overcome seasonal variation and when this is done the problem of a changing grass population enters into the situation if it is a grass mixture.

Cockayne (1), in writing of the production and earning power of New Zealand grassland, gives an average figure of 24 pounds of green grass per 24-hour day for sheep consumption, or roughly 4 tons per year.

Stapledon and Jones (6) devised a scheme for measuring the amount of grass consumed by sheep. A series of pens were arranged in which sheep were in alternate pens. All pens were treated alike

previous to grazing. The sheep were grazed for a period of five to six days and then removed. Both pens were harvested and the difference between the grazed and ungrazed pens was the amount the sheep consumed. Three records were taken by this method during the summer and a production of 6.03 tons of green grass from May 14 to August 17 calculated.

If the average consumption of an animal is known, the carrying capacity of a meadow might be determined by obtaining the production of green grass by repeated clippings, but this method has its objections.

## MILK FLOW

In measuring milk flow as a criterion for pasture production the age of the animals, hereditary complex, period of lactation, and stage of pregnancy of the different lots will influence the error of random sampling. The ideal arrangement would be to have animals of the same hereditary complex, of the same age, etc., but of course this is impossible so such conditions must be approached as near as possible.

Animals producing milk are usually fed a concentrated ration. Granting that the animals are all uniform as to period of lactation and pregnancy, they should all be fed a uniform concentrated ration or else none at all. Most dairymen will not agree to the latter. Furthermore, it is misleading because it is not the common practice, and the results would not be applicable. Feeding a uniform concentratedfration would more nearly approach the conditions of dairy management.

## PLANT POPULATION, PALATABILITY, AND DURATION OF GRASSES

These are all contributing factors to some of the other factors that have been discussed. They furnish an explanation for some of the results that have been obtained and are very valuable.

## CHEMICAL ANALYSIS

Chemical analysis is also an aid in explaining some of the results. Shutt, et al (3), in working with the protein content of grasses, chiefly meadow fox tail, state that the percentage of protein on a dry matter basis is highest when the grass is cut every week, but that the protein per acre is highest when cut every third week. They conclude that probably the cutting every third week contains the greatest amount of digestible protein.

It seems from this, therefore, that any analysis made as to the digestible protein of various grasses or the influence of fertilizers upon grasses should be made several times during the season, and that upon these results should be based the food value of the pasture.

## PROFITS

Three items should be considered in measuring profits, *viz.*, (a) increase in animal weight, (b) increase in milk flow, and (c) increase over investment and interest on investment. Data for these items are obtained by the methods previously discussed and a discussion of profits will not be taken up in detail. The data used in obtaining profits should all be obtained under similar conditions in order to make the results more valuable.

## CONCLUSION

There are many variable factors at work in pasture investigations, such as animals, soil, climate, grass population, etc. In order to reduce the error of random sampling, replications are necessary. The author hesitates to make any recommendations as to the number of replications that should be made because of the costs involved in such an extensive project. A project designed to obtain the basic results, i. e., animal weights, milk flow, or increased growth of meadow, should have four replications of plats with several control or check plats, and each plat should carry three animals. Other supporting and explanatory data, such as duration of grass, chemical analysis, etc., should be obtained under the conditions of the main project and at the same time.

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## DISCUSSION

Schuster has indicated the widespread interest in pasture investigations and the large attendance at this meeting may be considered additional evidence. Agronomists are aware of the fact, also, that in spite of the number of pasture investigations under way now, there are almost no published results giving quantitative returns in animal products from different systems of fertilization or of pasture management.

The problems have been largely attacked indirectly, as when attempts are made to determine the possible effects of fertilization of pastures from the returns from fertilizing mowing land. The increases from lime or fertilizer or from other treatments on meadows are not necessarily what would be secured if the land were pastured, and important as such data are, we can not be sure that under grazing conditions the results of different treatments will bear the same relation to each other, or whether the increases will be correspondingly great.

We need more evidence of the relation of the responses on permanent mowing land to those from similar treatments on grazed land. Among the most interesting results of such indirect investigations on pastures are the relative yields of grasses when cut as for hay or more frequently in imitation of pasturing, such as was done by Wiggans and by Stapledon, which showed the effect of number of cuttings upon total yield. Such investigations would be even more valuable if the forage cut under the different methods were analyzed for feeding constituents.

After all, the results in terms of maintenance and in animal products produced are of most value and seem to be the ultimate criteria for determining the value of any treatment. When we consider the difficulties of obtaining accurate

quantitative results as measured by animals, there is little wonder that results from comprehensive direct methods have been practically non-existent. We have been so taken up with the problems of reducing the errors of plat work that we are almost afraid of any simple field tests, and we have learned that the errors in feeding trials are such that the results from only a few animals in a group may be misleading. With this double hazard, if there are any number of comparisons, only a rather elaborate grazing experiment involving considerable expense can give worth while results.

In the evaluation of the treatments where stock are grazed it seems strange that in so few cases has the feed required for maintenance been credited to the treatments. In most feeding trials maintenance has been disregarded and the relative efficiency measured by the gains in flesh or milk or other products produced. The Connecticut Station, I understand, is crediting the pastures with what has been required for maintenance in addition to the gains in weight.
—CHARLES F. NOLL, *Pennsylvania State College.*

# 11A. THE EFFECT OF FERTILIZER TREATMENTS UPON THE QUANTITY AND QUALITY OF PASTURE VEGETATION: I. MINERAL TREATMENTS[1]

B. A. BROWN[2]

The treatments discussed under this heading deal for the most part with carriers of lime, phosphoric acid, and potash. No doubt, other minerals are essential for a good growth of pasture plants, but no data showing their importance have come to the writer's attention. Under a reasonable system of management, the soil is expected to, and evidently does, furnish whatever other mineral nutrients are necessary.

The experimental evidence bearing on this question will be considered in chronological order. Therefore, the classic pasture experiment (4, 7),[3] started in 1897 at Cockle Park, Northumberland County, England, will be discussed first. As this project is still on the active list, results are now available for 30 years, a really long period in comparison with other pasture experiments.

Ten 3-acre plats compose the layout at Cockle Park. The soil is described as a poor stiff clay, analyzing 4,000 pounds of nitrogen, 1,400 pounds of phosphorus, and 10,000 pounds of potash per acre. Bent grasses (*Agrostis* sp.) composed 61 % of the vegetation and only scattering plants of white clover were in evidence when the experiment was started. Without any cultural treatment or additions of seed, the several plats have been fertilized with various materials at regular intervals since 1897. The effects of the fertilizers are measured by determining the increases in live weight of sheep, which are used to graze the plats.

The treatments in the first period, 1897 to 1905, included lime and phosphorus alone and together. Potash was applied with phosphorus and phosphorus and lime, but not alone. Two applications, each of

[1]Paper read as part of the symposium on "Pasture Management Research" at the joint session of the New England Section of the Society and Section O of the A. A. A. S. held in New York City, December 28, 1928.

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[3]Reference by number is to "Literature Cited," p. 678.

4 tons of lime, increased the gains of the sheep only 35% during the first nine years, while two treatments with 700 pounds of superphosphate gave an increase of over 150% during the same period. Even better results were obtained when lime and phosphorus were applied together. Either basic slag or superphosphate plus lime approximately tripled the production of mutton.

Sulfate of potash at 300 pounds was added to the superphosphate treatment on one plat, but no increases were obtained. Muriate of potash at 100 pounds has been applied with basic slag every third year up to the present time, but basic slag alone has been just as effective.

If the results for the last nine years, 1919 to 1927, are compared with those from the first nine years, 1897 to 1905, it will be seen that the production of mutton on pasture treated with 500 pounds of basic slag per acre every third year is practically the same for both periods, while the unfertilized plat produced over 20% smaller gains during the last nine years. The basic slag treatment is equal to an annual application of about 30 pounds of phosphoric acid and 70 pounds of lime per acre. There are some indications that the basic slag need not be applied so frequently now. For example, a plat which had received 3,000 pounds of basic slag between 1911 and 1921, was divided, one-half receiving no fertilizer since 1921, and the other half being treated with 500 pounds of basic slag in 1924 and again in 1927. The gains of the sheep for the four years, 1924 to 1927, have been practically the same on both halves.

Also, there is some evidence from this experiment, that the liming of pastures may be overdone. A plat, which has received a ton of lime in addition to the 500 pounds of basic slag once in three years seems to be producing appreciably less during the last nine years than plats which have received basic slag only. To the writer's knowledge, the reasons for this apparent decrease from liming, if determined, have not been published.

The character of the herbage has been markedly changed by additions of lime and phosphoric acid. The bent grasses have been reduced from 60 to 30% of the total vegetation, and white (Dutch) clover increased so that it furnishes approximately 30% of the feed. The advantages of these changes in vegetation are brought out by the fact that twice as many sheep can be carried on the slagged as on the untreated land.

Demonstration plats throughout Great Britain have furnished corroborative evidence that phosphorus and lime are profitable pasture treatments under conditions suitable for white clover. On sandy or muck soils, potash, in conjunction with lime and phosphorus, has been of benefit.

In the United States, several experiments have been conducted to show the effects of mineral fertilizers on permanent pastures. The Virginia Station (5) and the U. S. Dept. of Agriculture cooperated in such an experiment for five years, 1913 to 1917, inclusive. Six 2½-acre plats were laid out on a bluegrass pasture in southwestern Virginia. Plat 1 received manure at 10 tons in 1913; plat 3, super-

phosphate at 300 pounds in 1913, 1915, and 1916; and plat 5, bone meal at 250 pounds in 1913, 1915, and 1916. Plats 2, 4, and 6 were not fertilized and served as checks. The effects of these treatments were measured by determining the gains of heifers or steers which were used to graze the plats.

The average increases in live weight over the adjacent plats were: For manure, 49%; for superphosphate, 87%; and no gain for bone meal. From these results, it is clear that a carrier of available phosphoric acid was very effective in increasing the productivity of a bluegrass pasture, in fact, much more effective than one-third as much phosphoric acid, plus 100 pounds of potash—the amounts assumed to be present in the 10-tons of manure. The Virginia workers stated that they were not able to explain the ineffectiveness of bone meal. Possibly, it was a question of availability, if raw bone meal was used. The English think the relatively poorer results from *dissolved* bones in the Cockle Park experiment to be due to the stimulating effect of nitrogen on the grasses at the expense of the clovers.

The effects of lime were not measured in the Virginia experiment, but from observation, the authors stated that lime greatly improved bluegrass pasture and recommended the equivalent of a ton of burnt lime per acre.

The West Virginia Station (2) fenced and treated four 1-acre plats with various fertilizer materials and grazed the areas with sheep. Due to the unequal productiveness of the plats before treatment, it is difficult to interpret the results. However, the authors state that lime alone did not improve the pasturage, while superphosphate with lime greatly increased the amount of white clover.

In 1924, Barnes (1) reported that in four counties in southeastern Ohio 2 tons of limestone and 400 pounds of superphosphate per acre increased the total vegetation three to five times and the crude protein five to seven times the amounts from untreated pasture. In most cases the herbage from the treated area had greater percentages of calcium and phosphorus. Legumes increased markedly after treatment, followed in a few years by an increase in bluegrass. According to the report, the effects of other than the limestone-superphosphate treatment were not measured.

From observation of variously treated plats on an old pasture, located on a light soil, probably Cheshire fine sandy loam, the Massachusetts Station (3) reported in 1926 that lime and superphosphate, either alone or together, were ineffective, while potash was the limiting factor. However, lime and phosphorus increased the productivity of the plats receiving potash. White clover came in thickly where effective treatments were applied.

In Pennsylvania, on plowed, reseeded fields, White and Holben (8) found that the yields of pasture grasses, cut as hay, were greatly increased by lime and phosphorus alone, but much larger yields were obtained when the two were applied together. On three different soil types potash added to lime and phosphorus produced appreciably more hay than lime and phosphorus without potash.

The Ohio Station (6) has reported the results from variously fertilized pasture plats which were clipped three times with a lawn mower in 1925, the year after fertilizers were applied. Superphosphate at 400 pounds did not increase the total yields appreciably, but did increase the clovers, while with 2 tons of limestone the reverse was true. Lime and phosphorus together were more effective and potash gave additional increases.

From extensive layouts on three New York pastures at different levels of fertility, Wiggans (9) found that superphosphate produced significant increases on all of the pastures, averaging 20% above adjacent untreated land. Lime gave an average increase of 100% on the poorer pastures and even on the best pasture, which had been limed previously, the gain was approximately 10%. Clover was greatly increased and weeds decreased by liming. Potash was used only on the poorest pasture and the inconsistency of the results do not warrant the drawing of conclusions.

The Connecticut (Storrs) Station[4] is conducting a grazing experiment to measure the effects of fertilizers on unproductive pasture land. The pasture on which this project is located is very stony, much too rough for any practical tillage operations, and in 1920, when the Station gained control, was largely covered with bushes and trees. The soil is a Charlton loam, quite retentive of moisture, andin round figures contained 6,000 pounds of nitrogen, 1,500 pounds of phosphorus, and 30,000 pounds of potassium per acre. Only traces of available phosphoric acid could be detected. The soil was very acid, having a pH of 5.2 and a CaO requirement of over 2 tons per acre. The sod on the open areas was thin and weedy, with only occasional Kentucky bluegrass or white clover plants.

After clearing the land, nine 4-acre plats were laid out and fenced in 1921 and 1922. Since then, these small pastures have been grazed each season by yearling beef steers and the production of pasturage is based on the maintenance and gains of the animals. In order to determine any differences before treatments, the plats were grazed for three years, 1921, 1922, and 1923, without treatments of any kind, except that bushes were mowed once each season. In the spring of 1924, eight of the plats were topdressed with various fertilizers, while the other was left untreated to serve as a check. The treatments include limestone at 2,000 pounds, superphosphate at 500 pounds. and muriate of potash at 100 pounds, both alone and in combination. The treatments of 1924 have been the only ones given to date. Results for five years are available at this time. These will be considered under three headings, *viz.*, effect on soil, effect on flora, and effect on the grazing animal.

*Effect on the soil.*—Tests of soil samples taken in 1926, two years after the treatments were applied, of the surface 2 inches and of the 2-to-6-inch level, showed that the limestone had reduced the acidity of the upper 2 inches by about 0.2 pH, but had had no apparent effect on the 2-to-6-inch horizon. Tests of the upper 2 inches for

[4]Unpublished data.

available phosphoric acid showed that small but significant increases had occurred on the plats receiving both limestone and superphosphate, while smaller and rather doubtful increases were evident on the plats receiving superphosphate only.

*Effect on flora.*—Although only small changes in the soil reactions have been detected, very marked changes have occurred in the flora of some of the plats. In 1927 and 1928, the plats receiving superphosphate were estimated to have 10 times as much white clover as the check plat, and limestone with superphosphate had increased the white clover 20 times, or to a point where it comprised nearly 40% of the herbage. Limestone and potash seemed to have increased the clover slightly, but the plants were stunted, due to the acute need for phosphorus.

Where increases in white clover have occurred, Kentucky bluegrass has spread also, while there has been a corresponding decrease in the less desirable grasses, like Danthonia and Sweet Vernal, and particularly there have been very marked decreases in weeds and bushes.

*Effect on animals.*—As might be expected, the carrying capacity and the gains of thecattle have paralleled the changes in herbage. Without phosphorus, only small increases have been obtained from any of the treatments. Based on the results from the unfertilized plat, the 500 pounds of superphosphate have produced an average increase of 64%, and the ton of limestone with superphosphate an additional increase of 56%.

The results from this experiment to date do not justify the conclusion that potash should be added to the superphosphate or superphosphate and lime treatments on soils of the same or similar types. There have been some indications that potash hastened the spread of white clover and increased production the second and third years after application. Possibly potash should be applied at more frequent intervals. However, most of the increase in pasturage has been due to superphosphate and lime.

The data which have been reviewed show that a lack of available phosphoric acid is usually the chief reason for the low level of production of pasture land in humid regions, and without adding a carrier of phosphorus little improvement may be expected. Lime has, as a rule, greatly increased the effectiveness of phosphorus carriers and inasmuch as many of the soils in humid regions are acid, it seems to be advisable to start the pasture improvement program by liming. In the Connecticut experiment there were indications that during the season of application the increases in pasturage from superphosphate were curtailed somewhat by the ton of limestone, although the lime was spread a few weeks before the phosphate. Others have observed similar results. The reasons for this have not been determined, but it may be due to the reversion of the soluble monocalcium phosphate to the relatively insoluble tri-calcium phosphate ($Ca_3(PO_4)_2$) at the very *surface* of the soil, thus retarding its distribution more than when the concentration of lime is not so great. Therefore, it is probably a good practice to lime at least a few months

before applying the phosphorus carrier, and also not to *topdress* with a sufficient amount of lime to *neutralize* the entire surface 6 inches of soil.

The evidence shows that in most instances little, if any, benefit has resulted from adding potash to phosphorus or phosphorus and lime. However, on lighter soils which, at present probably should not be used for permanent pasture anyway, it may be profitable to apply potash.

As to the amounts and frequency of applications of lime and phosphorus carriers, we have little to guide us with the exception of the English experiment. They seem to have obtained the maximum production from mineral fertilization for 30 years by adding 200 pounds of phosphoric acid and 400 pounds of CaO in basic slag once in six years. More data are needed on this point, particularly when nitrogenous fertilizers are applied with the minerals.

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# 11B. THE EFFECT OF FERTILIZER TREATMENTS UPON THE QUANTITY AND QUALITY OF PASTURE VEGETATION: II. NITROGEN TREATMENTS[1]

HENRY DORSEY[2]

A permanent pasture is a floral expression of a soil subjected to a long-continued grazing practice. By the application of fertilizers or by a change in grazing practices the flora may, in a very few years, be radically changed both in species represented and in chemical composition. Experiments showing the effect of fertilizers on pastures are not abundant but are of sufficient number, at least, to be quie suggestive of the values of the several nutrient elements.

The influence of nitrogen on plants is positive and of easy observation. It promotes vegetative growth, increasing the amount of stem and leaf, essential preliminaries to complete plant development. A lack of nitrogen results in a stunting of general growth and in the production of a relatively high proportion of seeds to the total weight of the plant. Upon analysis the plant, however, shows no marked deficiency of nitrogen (1).[3] Apparently, phosphorus, potassium, calcium, and other mineral nutrients are taken only in the amounts that can be used as determined by the supply of available nitrogen present.

One would expect the usual growth phenomena to occur in a pasture treated with the different nitrogenous fertilizer materials. However, the longest continued experiment on the treatment of a pasture will scarcely support this expectation.

At Cockle Park, in northeast England, in 1897, there was begun a pasture experiment that has continued to this time (2) in which sheep were grazed. This experiment was duplicated many times elsewhere in England, but for shorter periods of time. To one plat was applied 784 pounds of superphosphate per acre the first and fourth years in the first nine years of the experiment at Cockle Park and Sevington and the first year in three years at Yeldham. On another plat the same quantity of superphosphate was applied and in addition in the first, third, fourth, and seventh years, 84 pounds of sulfate of ammonia per acre at Cockle Park and 97 pounds at Sevington were applied. At Yeldham there were applied 100 pounds of sulfate of ammonia the first and second years and 200 pounds the third year.

The outcome of the treatment is given in Table 1, and shows a loss of 27 pounds of mutton at Cockle Park for the application of 336 pounds of sulfate of ammonia. Similarly, at Sevington the loss was 124 pounds of mutton for the use of 398 pounds of the nitrogen carrier. At Yeldham in three years 400 pounds of sulfate of ammonia accounts for a gain of 24 pounds as compared with the use of superphosphate alone.

[1]Paper read as part of the symposium on "Pasture Management Research" at the joint session of the New England Section of the Society and Section O of the A. A. A. S. held in New York City, December 28, 1928.

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[3]Reference by number is to "Literature Cited," p. 684.

TABLE 1.—*Aggregate live weight increase in pounds per acre due to manures.*

| Fertilizer | Cockle Park, 9 years | Sevington, 9 years | Yeldham, 3 years |
|---|---|---|---|
| 7 cwt. superphosphate 1st and 4th years at first two and 1st year at last....... | 513 | 402 | 54 |
| Superphosphate and sulfate of ammonia in addition........................ | 486 | 278 | 78 |
| Loss or gain for nitrogen.............. | —27 | —124 | +24 |

At Cockle Park nitrate of soda was substituted for sulfate of ammonia the tenth year. In 1906 and 1909, 139 pounds were used, while but 112 pounds were applied in 1912, 1915, and 1918. Superphosphate at the first rate was applied every third year after 1906 on both plats. During the 15 years the superphosphate plat gave 1,340 pounds per acre of mutton gain above an untreated check, while the plat receiving both fertilizer materials gave but 1,125 pounds gain, a loss of 215 pounds or 14 1/3 pounds annually per acre. In 1926, the two fertilizers were still producing less mutton than the superphosphate alone. As a business venture the use of sulfate of ammonia and nitrate of soda at Cockle Park has proved to be not only useless but positively harmful.

At Cockle Park and at Sevington dissolved bones containing perhaps 3% nitrogen have been compared with basic slag alone and with superphosphate alone so used as to supply equal amounts of phosphoric acid in each of the three treatments (2).

TABLE 2.—*Comparison of three phosphates on pasture for nine years.*

| Treatment | Live weight increase in pounds Cockle Park | Sevington |
|---|---|---|
| 560 pounds basic slag applied the first and fourth years.................................. | 594 | 405 |
| 784 pounds superphosphate applied the first and fourth years............................ | 513 | 402 |
| 672 pounds dissolved bones applied the first and fourth years............................ | 553 | 342 |

The data are given in Table 2. At Cockle Park the dissolved bones were slightly better than superphosphate but poorer than basic slag.

At Sevington the dissolved bones gave lower mutton gains than either of the other phosphorus carriers. The experiment has been continued at Cockle Park. During 15 years basic slag has produced a net gain of 1,340 pounds per acre of mutton and dissolved bones only 1,036 pounds. In this experiment the use of nitrogen containing dissolved bones can not be justified upon any grounds whatever.

Again at Cockle Park, fish meal has been added to pasture land laid out in 10-acre plats in comparion with basic slag and the grass has been grazed by a mixed stocking of sheep and cattle. Plat 1 received 560 pounds of basic slag per acre every third year, while plat 4 received 448 pounds and an additional 392 pounds of fish meal to give an equal amount of phosphoric acid to each plat but considerable additional nitrogen to plat 4.

The outcome for 15 years is presented in Table 3. During the early years the fish meal was beneficial, but as time advanced it fell behind and for the period gives a net loss of 153 pounds per acre of live weight increase.

TABLE 3.—*Average live weight increase in pounds per acre per year and total gain for 15 years.*

| Period | Years | Plat 1 560 pounds basic slag every third year | Plat 4 448 pounds basic slag and 392 pounds fish meal every third year |
|---|---|---|---|
| 1st | 1906–08 | 206 | 225 |
| 2nd | 1909–11 | 187 | 187 |
| 3rd | 1912–14 | 189 | 190 |
| 4th | 1915–17 | 200 | 179 |
| 5th | 1918–20 | 229 | 179 |
| Total gains for period | | 3,033 | 2,880 |

The feeding of nitrogenous concentrates to sheep and other grazing livestock has long been advocated. It is supposed to increase the flesh production as well as to improve the pasture through the effect of the manure resulting from the feeding of the concentrates. At Cockle Park cotton cake has been fed for a period of three years on one lot and then suspended for three years. The live weight increase has usually been insufficient so pay for the feed used. Further, while there has been a consistent live weight increase, the increase has fallen below that made through the use of basic slag alone.

When the feeding has taken place on slagged land the live weight increase has been much larger but not great enough to justify the use of cotton cake. In 17 years this gain amounted to 593 pounds secured through feeding 5,712 pounds of cake.

This series of experiments at Cockle Park has been carried out on a poor heavy soil resting on Bowlder Clay. One would expect such a soil to respond to available nitrogen, which it has done in fact. However, it must be added that the response has been greater and profitable only when it has been secured through the nitrogen fixed by clover and other legume bacteria stimulated by non-nitrogenous fertilizers. The phosphates have stimulated the clover growth and its nitrogen supply has, in turn, promoted the growth of the desirable grasses to a far greater extent than has any form of nitrogenous fertilizer used in the experiments. A supply of applied nitrogen has suppressed clover and has promoted a coarse sort of grass growth that is probably unpalatable and unwholesome.

A trial of feeding some hays grown under different fertilizer treatments at Cockle Park (3) is significant even though not pasture. For 21 years the same fertilizer was applied to the land originally a pasture. During three of the years the hay from the different plats was fed to sheep and its value thus determined. Table 4 gives the treatments, annual yields, and value per ton as feed for sheep.

The outcome is that nitrogen in every instance depresses the value of the hay and phosphorus increases its value remarkably. Further, the nitrogen while it increases the yield is not outstanding in this respect.

This feeding trial with hay suggests that quality should be sought as well as quantity. In Scotland (4) a beginning in this respect has been made with pasture. Analyses of grass from good and poor pastures have shown the good grass to contain much total ash, lime, phosphoric acid, potash, chlorine, and nitrogen, while poor grass was low in these constituents and high in fiber. Further, grass taken from

TABLE 4.—*Average yield and feed value of hays grown with different fertilizers.*

| Plat No. | Annual fertilizer treatment, 21 years | Yield per acre, 21 years, cwt. | Value as feed, English S d |
|---|---|---|---|
| 6 | Untreated | 19¼ | 80/0 |
| 7 | 30 pounds N as sulfate of ammonia | 23 | 72/0 |
| 8 | 50 pounds $P_2O_5$ as basic slag | 26 | 93/0 |
| 9 | 50 pounds $K_2O$ as muriate of potash | 16 | 80/0 |
| 10 | 30 pounds N and 50 pounds $P_2O_5$ | 30¼ | 84/0 |
| 11 | 30 pounds N and 50 pounds $K_2O$ | 21 | 72/0 |
| 12 | 50 pounds $P_2O_5$ and 50 pounds $K_2O$ | 26 | 101/9 |
| 13 | 30 pounds N, 50 pounds $P_2O_5$, and 50 pounds $K_2O$ | 30½ | 89/2 |

eaten spots in a pasture was also high in these same constituents, while uneaten grass was low in the minerals and high in fiber.

Likewise, observations in Scotland (5) and elsewhere have shown sheep to become unwell on certain pastures and to thrive on others. They develop a rachitic disease called "bent-leg," become lethargic, and develop swollen joints, but show little evidence of pain. The condition has been attributed to dietary troubles. In feeding experiments the same symptoms have been induced in four or five months by rations lacking minerals. This disease does not develop upon slagged pastures. Nitrogenous fertilizers have not been investigated, but it is surmised that they alone might aggravate the trouble. Somerville's feeding trials would at least suggest caution in the use of nitrogen for the highest quality of pasturage.

The Rothamsted (6) hay experiments also throw some light upon the influence of nitrogen on grass. Nitrate of soda increases the yield of hay as does sulfate of ammonia. The growth, however, is not satisfactory. With complete minerals these nitrogenous fertilizers give a very large growth of grass. This growth is coarse and woody and is inclined to lodge. The clover and other legumes are depressed and often eliminated, particularly by sulfate of ammonia. This is evidence similar to that of the pasture treatments just mentioned.

Pasture experiments in America are not numerous. However, at the Cornell Experiment Station (7) in one experiment 32 plats in a total of 48 received nitrate of soda. These were clipped with a lawn mower equipped with a carrier. During three of the four years for which data are available the clippings were separated by groups into grasses, clovers, and weeds. A summary of this finding is given in Table 5. The results are that the grasses have benefited most and the clover least. The author concludes that nitrogen had better be supplied to pasture through the stimulation of clover growth.

Manure was used on another series of plats (7) and the outcome is markedly favorable to the use of this product. It increased yields, stimulated clovers and grasses, and caused a slightly deferred grazing due to the animals avoiding the manured herbage.

In Virginia (8) superphosphate at the rate of 300 pounds per acre, manure at 10 tons, and bone meal at 250 pounds were compared on 2½-acre lots grazed by cattle. The four year total increase for the superphosphate was 632 pounds and the manure increase, 468 pounds. The bone meal returned a gain 14 pounds less than the check plat. Thus, in Virginia, such nitrogen as was used was ineffective.

TABLE 5.—*Effect of nitrate when various treatments are compared.*

| Vegetation | Number of years | Average of all plats receiving nitrate in pounds per acre | Average of all plats not receiving nitrate in pounds per acre | Gain in pounds per acre | Gain % |
|---|---|---|---|---|---|
| | | Green Weight | | | |
| Total...... | 3 | 2,828 | 2,406 | 422 | 18 |
| Total...... | 4 | 3,149 | 2,716 | 433 | 16 |
| Clover..... | 3 | 673 | 660 | 13 | 2 |
| Grass...... | 3 | 1,044 | 813 | 231 | 28 |
| Weeds..... | 3 | 1,110 | 932 | 178 | 19 |
| | | Dry Weight | | | |
| Total...... | 3 | 1,034 | 877 | 157 | 18 |
| Total...... | 4 | 1,032 | 890 | 142 | 16 |
| Clover..... | 3 | 268 | 256 | 12 | 5 |
| Grass...... | 3 | 356 | 277 | 79 | 29 |
| Weeds..... | 3 | 410 | 344 | 66 | 19 |

Unpublished data at the Connecticut (Storrs) Experiment Station for the years 1927 and 1928 show a 4-acre lot treated with 500 pounds per acre of superphosphate and 100 pounds of muriate of potash once in 1924 to maintain 660 pounds of steer per day for a 150-day season. When 1 ton of limestone per acre was added on another lot in addition to the same minerals the maintenance was 1,062 pounds of steer per day for the season, or an increase of maintenance of 61%. Another lot received the same minerals as the first in 1924, and in addition, 150 pounds of nitrate of soda in 1924, 1927, and 1928. Its production was exactly equal in 1927 and 1928 to that of the lot that received the minerals and limestone in 1924. The nitrogenous fertilizers as here used served no better than limestone and they were applied three times in five years.

TABLE 6.—*Average annual yields of pasture hay per acre on three Pennsylvania soils.*

| Treatment | Snow Shoe County, 1916–24 | Washington County, 1918–24 | Bradford County, 1918–24 |
|---|---|---|---|
| Nearest untreated.................. | 443 | 1,966 | 884 |
| Ca to neutrality, 65 pounds $P_2O_5$, 50 pounds $K_2O$..................... | 3,290 | 3,567 | 3,767 |
| Same as last and 48 pounds N as nitrate of soda.......................... | 4,236 | 4,888 | 4,702 |
| Increase for nitrate................. | 946 | 1,321 | 935 |

At the Pennsylvania Station (9) the addition of nitrate to minerals has been compared in the production of pasture hay (not pasture) on three soil types where the soil is quite poor and run down. The data have been assembled in Table 6 to show the influence on the production of pasture hay when harvested at the late bloom stage of Kentucky bluegrass. The outcome shows an increase of about half a ton of hay, consisting largely of bluegrass but containing both sweet clover and weeds. The increase was probably significant, but it is not a pasture increase.

A pasture experiment (10) at the School of Agriculture, Cambridge, England, while untreated with any fertilizer, is so outstanding in its nutritive value that mention should be made of it. Here the grass was clipped once per week during the entire season for three successive years. This young grass had a digestibility of about 80% for the dry

matter, while the digestibility of the carbohydrate and protein was well above this figure. The nutritive ratio was 1 of protein to less than 3 of the carbohydrate equivalent. Furthermore, under this close clipping the white clover assumed a very commanding position in the pasture flora as if the land had had a dressing of basic slag. Moreover, the high digestibility of the nutrients brought the effective yield to a point equal to or better than that of a hay crop.

Thus, it appears that the method of harvesting (grazing) may give an account of itself similar to fertilizer treatments. It is realized that these data on composition and digestibility are somewhat foreign to the subject in hand, but they are thought to be worthy of inclusion since it may be that quality in grass is of far more significance than we have surmised.

More recently, the treatment of pastures after the Hohenheim manner with very large amounts of nitrogen in four parts per season and smaller amounts of superphosphate and potash are reported (11, 12) to give a phenomenal and outstanding production of herbage. The method requires rotation and close grazing to be practiced. White clover is said to maintain itself well under the system which is contrary to expectation after the experiences with smaller amounts of nitrogen applied with superphosphate.

In conclusion, it may be said that the early experiments on the use of nitrogen alone or with minerals has cast much doubt upon its real value. The use of the cheaper minerals has induced clover and other legume growth. This growth has, in turn, been followed by a heavy grass growth, due no doubt to the accumulated nitrogen fixed by the bacteria in the clover and other legume nodules. This system of fertilization of pastures has been effective in giving high production for a period of more than 30 years.

Heavy annual treatments of nitrogen and lighter applications of phosphoric acid and potash on pastures in Germany, England, and Massachusetts are giving exceedingly large returns. This type of treatment has not been directly compared with the use of minerals alone. No doubt it will soon find its proper position in our agricultural practice.

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## DISCUSSION

The papers by Brown and Dorsey may be briefly summarized as follows: (1) Available phosphoric acid is the first limiting factor in pastures, (2) lime increases the effectiveness of phosphoric acid, and (3) practically no benefit is to be expected from potash or nitrogen. If these conclusions are accepted, there can be little use for further pasture fertilizing experiments. There are indications, however, that these conclusions are not of as wide application as has been assumed.

While available phosphoric acid is usually the first limiting factor in pastures, it is highly variable when it comes to increasing productivity. For example, at Cockle Park it increased the hay yields 100%, while on the Turkey Hill plats at Cornell there was practically no increase in yield. Using livestock as a means of measurement at Cockle Park, it gave an increase of 153% in the live weight of sheep. At Storrs, Conn., using the thermal basis of measurement, the gain was 64% with steers; while at Virginia the gain in the live weight of steers was 87,40, or 11%, depending on the check plat used for comparison.

Lime apparently is very consistent in increasing the effectiveness of phosphoric acid. At Cockle Park it increased the hay yield 25% and maintained a decidedly higher percentage of clover in the stand. Here it also gave an increase of 60% in the live weight of sheep. At Storrs it gave a 56% thermal gain when steers were used.

There are several objections to accepting the conclusions offered for the use of potash and nitrogen in pastures, *viz.*, (1) failure to remove the phosphorus and lime limiters have not given potash and nitrogen a fair chance; (2) the amounts of these elments used have been too small to give results measureable by the methods employed; and (3) use of steers and sheep to harvest the herbage creates a far different drain on plant food than dairy cows which void a large part of the plant food removed from the pasture in the barn or in night pastures. Under farm conditions this plant food, mostly nitrogen and potash, is returned to crop land, not to pasture.

Potash at Cockle Park, on a stiff clay notoriously high in potash, did not increase the live weight of sheep when added to phosphoric acid but did give the highest feed value of hay, even though the lime limiter was not removed. On the Bald Hill (N. Y.) plats potash improved the quality of the herbage when the lime limiter was removed, even though the amount of potash used was very small. At Storrs, Conn., potash added to phosphoric acid (lime limiter not removed) gave an increase of 8%, the average of five years. Taking the first three years, the gain for potash is 24.5% which indicates that the interval between applications is too great for the amount of potash used.

White at the Pennsylvania Station, after removing the phosphorus and lime limiters, got the following increases of Kentucky bluegrass from the use of potash: Westmoreland, 8%; DeKalb, 21%; and Volusia, 46%, which indicates that soil type must be considered in drawing conclusions. At the Massachusetts Station potash added to lime and phosphoric acid increased the dry matter 75% and the protein 185%. Morgan at the Connecticut Station, using tobacco as an indicator crop, showed that 22 of the 24 Connecticut soils displayed marked deficiencies of available potash. Since the lime and phosphorus limiters have not been removed in many experiments, since sheep and steers have been used to measure results, and since too little potash has been used, if any, the existing experiments do not justify the sweeping conclusion that potash is not needed on pastures.

At Cockle Park lime was not added to the nitrogen plat, even though the work showed that lime was a limiter. The need for lime was intensified in the early

part of the experiment by use of sulfate of ammonia. White at the Pennsylvania Station got the following increases from nitrogen on Kentucky bluegrass after the lime, phosphorus, and potash limiters were removed: Westmoreland, 39%; DeKalb, 40%; and Volusia, 54%. Skinner and Noll at the same station also established the high response of Kentucky bluegrass to nitrogen. In their work they showed that while red clover disappeared from the 21 high-nitrogen plats, white clover persisted on all but 3. At Storrs nitrogen added to phosphorus and potash gave an average gain of only 8% (five-year average). Nitrogen, however, was applied only in three of the five years. Comparing these plats, the three years the nitrogen ws applied the gain for nitrogen was 46%.

In addition, the results secured from the Hohenheim system casts considerable doubt that nitrogen is of little or no value for pastures. This system uses the experimental indications of the value of rotation grazing, close grazing, and the use of liberal quantities of lime, phosphorus, and potash to balance the application of nitrogen. The nitrogen increases the volume of existing herbage, particularly the grasses, and does not eliminate the white clover.—R. A. PAYNE, *Northampton, Mass.*

## 12. THE CHEMICAL COMPOSITION OF GRASS FROM PLOTS FERTILIZED AND GRAZED INTENSIVELY[1]

J. G. ARCHIBALD AND P. R. NELSON[2]

### INTRODUCTION

Research on problems of pasture improvement is not a recent development, having attracted the attention of American as well as foreign experiment stations soon after they were founded. The earlier work, however, was confined in large measure to empirical manuring and fertilizing tests, with only sporadic attempts to study the effects of such treatment and of grazing on the botanical and chemical composition of the herbage. While not wishing to minimize in any way the importance of this earlier work, limitations of space require that we pass along to the more recent intensive studies, made largely in England and Germany and stimulated in large measure, no doubt, by the introduction into Germany during the World War, and later into England, of an intensive system of nitrogenous fertilizing and grazing of grass lands.

Among the more important of these recent researches are those carried on by Woodman and his colleagues at the School of Agriculture at Cambridge University, England; by Stapledon and his associates at the Welsh Plant Breeding Station, Aberystwyth, Wales; by various members of the staff of the Rowett Research Institute, Aberdeen, Scotland; by Shutt and his co-workers at the Dominion Experimental Farm, Ottawa, Canada; and by Aston in New Zealand. The findings of these workers have all been published within the past four years, a fact which reveals the great stimulus the work has lately received.

[1]Paper read as part of the symposium on "Pasture Management Research" presented at the joint session of the New England Section of the Society and Section O of the A. A. A. S. held in New York City, December 28, 1928. Additional data included for publication. Published with the permission of the Director of the Massachusetts Agricultural Experiment Station.

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Woodman, et al (1, 2, 3)[3] conclude that the dry matter of closely grazed pasture is to be regarded as a protein concentrate of high digestibility and nutritive value and that because of its low content of indigestible fiber it should not be classed with the coarse fodders.

At the Rowett Research Institute the mineral content of pasture grass has received special attention (4, 5, 6). It has been found that there are marked differences in this respect, the herbage of the hill pastures being in general much poorer in ash than that of cultivated pastures. A definite seasonal variation also exists, most marked in the case of CaO, which rises to a maximum in the late summer and then falls steadily. Application of fertilizer to grass land may result in considerable modification of the mineral content of the herbage, the greatest variations being in calcium and potassium and, to a lesser extent, in phosphorus.

Shutt, et al (7) have investigated the protein content of grass as influenced by frequency of cutting, i.e., simulation of close grazing, and conclude that the shorter the period of growth the higher the percentage of protein in the grass. To quote *verbatim*, "frequent cutting results in the production of a grass which in respect to nutritive value has the characteristics of young grass—high protein and low fibre."

Mention should also be made of the work done in this country some years ago by Forbes (8) in Ohio on the mineral nutrients in bluegrass; by Ellett and his co-workers (9, 10) in Virginia on a phase of the subject similar to that reported by Shutt, et al; and by Barnes (11) in Ohio.

An intensive system of grassland management was introduced into Massachusetts during this present season (1928) with the organization of an experiment conducted on the Massachusetts Agricultural College farm. The chemical work done on this project forms the basis of this paper.

## EXPERIMENTAL

The tract of land chosen for the experiment is for the most part quite level meadow land, part of which has been in grass for several years, while part has only recently been seeded. It would be considered very good pasture. The soil is a medium loam grading to a silt loam. The total area is 74 ¼ acres, which was divided and fenced off into nine plots of 8 ¼ acres each. Table 1 shows the scheme of fertilization.

These combinations and rates of application are equivalent in all cases to 85 pounds of nitrogen (N), 55 pounds of phosphoric acid ($P_2O_5$), and 67 pounds of potash ($K_2O$) per acre. Note that 30 pounds of the nitrogen were applied as the season progressed, in three separate applications of Calurea, each equivalent to 10 pounds of nitrogen.

The entire college dairy herd (exclusive of cows on advanced registry test) was made available for the experiment and was divided into three groups as follows: (a) High producers, which were always given the first, and therefore, choice grazing from each plot; (b) low producers, which followed the high producers in the rotation; and

[3]Reference by number is to "Literature Cited," p. 699.

TABLE 1.—*Kind of fertilizer, rate, and date of application in Massachusetts experiment.*

| Plot No. | Kind of fertilizer | Rate of application in pounds per acre | Date of application |
|---|---|---|---|
| 1, 2, 3, 5, 6 | Nitrophoska II | 334 | Apr. 20–May 5 |
| | Calurea | 30 | At intervals throughout the season, varying from 30 days to 58 days, commencing May 28, ending Sept. 6 |
| | Calurea | 30 | |
| | Calurea | 30 | |
| 7, 8, 9 | Nitrophoska I, 41%* Calcium nitrate, 41% Muriate of potash, 18% | 440 | May 7 and 8 |
| | Calurea | 30 | At intervals throughout the season, varying from 20 days to 66 days, commencing June 21, ending Sept. 15 |
| | Calurea | 30 | |
| | Calurea | 30 | |
| 4 | Check | no fertilizer | |

*The difference in fertilization of certain of the plots (7, 8, 9) was one of the vicissitudes of the experiment. The shipment of "Nitrophoska" when received instead of being all "Nitrophoska II" was partly "II" and partly "I". As there was not time to order more of the "II" a mixture and rate of application was formulated from "I", calcium nitrate and muriate of potash, which supplied the same amounts per acre of N, $P_2O_5$, and $K_2O$ as did the "Nitrophoska II." This variation resulted, however, in a much larger application of calcium to plots 7, 8, and 9 (68 pounds CaO as compared with 12 pounds on the other plots), a difference which is reflected in the calcium content of the grass from these plots and which will be discussed later.

(c) dry cows and young stock which completed the grazing, following which each plot was given a rest period of several days.

Systematic sampling[4] for chemical analyses of the herbage on each plot was carried on throughout the season which extended from May 14 to October 26. All samples were taken at the conclusion of the rest period for each plot just before the cattle were turned into the plot. The sampling procedure was as follows: Six points were taken in each plot, three on each of its long dimensions, equi-distant from each other, and one-third of the width of the plot from its edge. The points on each plot were not taken opposite each other but were "staggered." At each point a hollow wooden square with an inside area of 4 square feet was dropped on the grass and all herbage inside the square was cut with grass shears as closely as it was considered that cattle would graze, care being taken not to include any soil or grass roots. The points at which the samples were taken were conveniently marked at the beginning of the season so that it was possible to return to the same point for subsequent sampling. The system was planned with the idea of eliminating, as far as possible, the personal element in sampling, the square in each case being dropped impartially at a point one-third of the width of the field from the marked post on the margin. Occasionally the sampler had to use his judgment, for obviously it would not be wise to take a sample in a wet spot where the grass had been killed out, or where cattle droppings had fallen. It is felt that by this system reasonably representative samples of the herbage were secured with a minimum of time expended.

[4]Acknowledgment is made of the services of C. H. Parsons of the Animal Husbandry Department of the college who did most of the sampling.

The grass as soon as cut was placed in an oilcloth container and when all of the six areas in the plot had been clipped the composite sample was weighed at once, run through a power hay cutter, thoroughly mixed, and subsampled, the subsample being placed in a glass-stoppered, wide-mouthed gallon jar and taken to the laboratory where moisture was determined immediately in 20-gram aliquots. The bulk of the sample was then air dried in a thin layer, ground, and again carefully subsampled for analyses. The determinations made were total nitrogen, crude fiber, ether extract,[5] calcium, and phosphorus.

The results will be discussed from two angles, *viz.*, effect of the fertilizer and seasonal variations. The results for the fertilized plots have been separated into two groups, plots 1, 2, 3, 5, and 6 appearing in one group and plot 7, 8, and 9 in the other. There are three reasons for this as follows: (a) The fertilizer treatment was slightly different, as shown by Table 1; (b) plots 7, 8, and 9 were not grazed during the early part of the season, being reserved for supplementary grazing acreage later in the summer (an inherent feature of the system), the grass on them being cut for hay early in June; and (c) these three plots had been more recently seeded and the turf on them was not so well established as on the others, and also they contained a considerably higher proportion of "top" grasses.

Results for nitrogen in all cases are expressed on a "total nitrogen" basis, and not as protein, as it is felt that a considerable amount of the nitrogen may have been in the non-protein form.

All results are expressed in two ways, *viz.*, on a "dry matter" basis and on a "pounds per acre" basis. Caution should be used in attaching significance to the latter mode of expression, for due to obvious limitations in the method of sampling the chance for error is considerable. Also, because, with the method of sampling used, the amount of growth during the time when the cattle were actually grazing any particular plot could not be ascertained, the figures given do not represent total production for the season, but are averages of the weights of the crop at the several times of sampling. However, they are at least relative. Table 2 shows the effect of fertilizing.

In any study of these results it must be remembered that plots 7, 8, and 9 grew a crop of hay, analyses of which obviously should not be included here, and that conditions for new growth of "bottom" grasses on these plots after the hay was cut were very unfavorable, for, due to an abnormally wet haying season, the hay lay on the plots not less than 15 days and in one case for 24 days.

Comparing the check plot with the first group of fertilized plots, the following will be noted:

1. The grass on the check plot contained approximately 22% more dry matter. On the other hand, the average yield of dry matter on the dates when the samples were taken was about 32% greater on the fertilized plots.

[5]The determinations of crude fiber and ether extract were made in the Feed Control laboratory of this station by M. W. Goodwin and J. W. Kuzmeski under the direction of P. H. Smith, Chief Chemist of the Feed Control.

TABLE 2.—*Effect of fertilizing on the chemical composition of the grass.*

| Group | Dry matter % | Dry matter Pounds per acre | Nitrogen In dry matter % | Nitrogen Pounds per acre | Crude fiber In dry matter % | Crude fiber Pounds per acre |
|---|---|---|---|---|---|---|
| Plots 1, 2, 3, 5, 6: | | | | | | |
| Average of 26 samples | 26.7 | 1,011 | 2.8 | 28.6 | 23.5 | 238 |
| Nitrophoska II | | | | | | |
| Calurea | | | | | | |
| Plots 7, 8, 9: | | | | | | |
| Average of 13 samples | 26.1 | 675 | 3.0 | 20.2 | 22.3 | 151 |
| Nitrophoska I | | | | | | |
| Calcium nitrate | | | | | | |
| Muriate of potash | | | | | | |
| Calurea | | | | | | |
| Plot 4 (check): | | | | | | |
| Average of 5 samples | 32.6 | 768 | 2.2 | 16.8 | 25.0 | 192 |
| Unfertilized | | | | | | |

| Group | Ether extract In dry matter % | Ether extract Pounds per acre | Calcium In dry matter % | Calcium Pounds per acre | Phosphorus In dry matter % | Phosphorus Pounds per acre |
|---|---|---|---|---|---|---|
| Plots 1, 2, 3, 5, 6: | | | | | | |
| Average of 26 samples | 3.3 | 33.1 | 0.50 | 5.0 | 0.33 | 3.3 |
| Nitrophoska II | | | | | | |
| Calurea | | | | | | |
| Plots 7, 8, 9: | | | | | | |
| Average of 13 samples | 3.4 | 23.2 | 0.58 | 3.9 | 0.28 | 1.9 |
| Nitrophoska I | | | | | | |
| Calcium nitrate | | | | | | |
| Muriate of potash | | | | | | |
| Calurea | | | | | | |
| Plot 4 (check): | | | | | | |
| Average of 5 samples | 3.0 | 22.9 | 0.53 | 4.1 | 0.30 | 2.3 |
| Unfertilized | | | | | | |

2. There was 27% more nitrogen in the dry matter from the fertilized plots and about 70% more nitrogen was produced per acre.

3. There was about 6% more fiber in the dry matter from the check plot, but the acre production of fiber was about 24% greater on the fertilized plots.

4. The ether extract in the dry matter was about 10% higher on the fertilized plots and its production per acre was about 45% higher.

5. The percentage of calcium in the dry matter was slightly lower on the fertilized plots, although the actual amount of calcium per acre was somewhat higher, about 22%. Contrast this with the calcium figure for plots 7. 8, and 9, which is markedly higher than in either the check plot or the other group which was fertilized. This difference, if traceable at all to the fertilizer treatment, is probably due to the much heavier application of calcium these three plots received.

6. The phosphorus content of the dry matter from plots 1, 2, 3, 5, and 6 was 10% higher than that from the check plot, while the average production per acre was about 42% higher. It is probably useless to speculate as to why the phosphorus content was lower on plots 7, 8, and 9, than on the check plot.

Reasons already mentioned can be assigned for the lower average production of dry matter, calcium. and phosphorus on these three

plots than on the check, *viz.*, a poorer turf, part of the production represented by a hay crop, and adverse conditions for re-establishment of the growth of "bottom" grasses after the hay was cut.

The higher nitrogen content of the dry matter in comparison with plots 1, 2, 3, 5, and 6 is possibly explained by the fact that these plots (7, 8, and 9) were seeded more recently and in consequence the herbage from them may have contained a higher proportion of clover, or what is more likely, the lower total yield may have resulted in a higher nitrogen content as is sometimes the case.

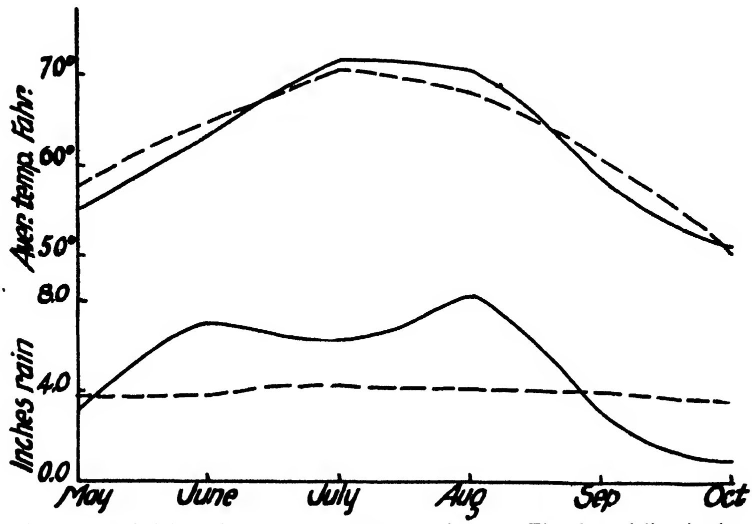


FIG. 1.—Rainfall and temperature, season of 1928. The dotted line is the normal for Amherst.

Summarizing briefly, the dry matter of the grass from the fertilized plots was higher in total nitrogen, ether extract, and phosphorus, and lower in crude fiber and calcium than the dry matter of the grass from the check plot. Acre production of all constituents determined was higher, and in most cases markedly so, on the fertilized plots than on the check plot.

Table 3 shows the seasonal variations in the several constituents determined. Fig. 1 presents the rainfall and temperature record for the growing season, factors which are of importance in any study of seasonal variations in plant growth.

Variations in the several constituents are considered in detail below.

## DRY MATTER

With respect to percentage fluctuations in dry matter, the situation is much the same for all the plots, *viz.*, a relatively high dry matter content at the beginning of the season, due in part at least to presence of dead grass from the previous season's growth; a drop to a somewhat lower level in the succulent June growth; a marked increase during the heat of midsummer, followed by another drop through

TABLE 3.—*Seasonal variations in composition of pasture grass.*

| Month | Dry matter % | Dry matter Pounds per acre | Nitrogen In dry matter % | Nitrogen Pounds per acre | Crude fiber In dry matter % | Crude fiber Pounds per acre | Ether extract In dry matter % | Ether extract Pounds per acre | Calcium In dry matter % | Calcium Pounds per acre | Phosphorus In dry matter % | Phosphorus Pounds per acre |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Plots 1, 2, 3, 5, and 6 | | | | | | | | |
| May | 24.2 | 544 | 4.1 | 22.5 | 16.0 | 87 | 3.6 | 19.7 | 0.44 | 2.4 | 0.40 | 2.2 |
| June | 20.5 | 1,331 | 2.8 | 37.8 | 25.4 | 338 | 2.9 | 38.3 | 0.43 | 5.7 | 0.39 | 5.2 |
| July | 26.6 | 1,157 | 2.3 | 26.6 | 28.2 | 326 | 2.8 | 32.7 | 0.48 | 5.5 | 0.32 | 3.7 |
| Aug | 25.7 | 1,154 | 2.6 | 29.8 | 25.8 | 297 | 3.7 | 42.2 | 0.50 | 5.8 | 0.31 | 3.6 |
| Sept | 22.8 | 1,060 | 3.0 | 32.1 | 23.5 | 249 | 3.6 | 37.6 | 0.54 | 5.8 | 0.33 | 3.5 |
| Oct | 35.8 | 807 | 2.2 | 17.6 | 23.6 | 190 | 3.2 | 25.4 | 0.58 | 4.7 | 0.27 | 2.2 |
| | | | | Plots 7, 8, and 9* | | | | | | | | |
| May | 29.0 | 439 | 4.0 | 17.8 | 16.9 | 74 | 3.4 | 15.0 | 0.63 | 2.8 | 0.31 | 1.4 |
| June† | — | — | — | — | — | — | — | — | — | — | — | — |
| July | 23.1 | 690 | 2.9 | 20.0 | 26.2 | 181 | 3.1 | 21.6 | 0.53 | 3.6 | 0.31 | 2.1 |
| Aug | 24.5 | 733 | 2.7 | 19.6 | 24.0 | 176 | 3.7 | 26.8 | 0.55 | 4.0 | 0.29 | 2.1 |
| Sept | 23.3 | 759 | 2.6 | 19.9 | 21.8 | 166 | 3.5 | 26.5 | 0.59 | 4.5 | 0.26 | 2.0 |
| Oct | 31.4 | 695 | 2.4 | 16.5 | 22.8 | 158 | 3.5 | 24.1 | 0.63 | 4.4 | 0.22 | 1.6 |
| | | | | Plot 4 (Check)‡ | | | | | | | | |
| May | 32.9 | 299 | 2.9 | 8.5 | 17.1 | 51 | 3.4 | 10.2 | 0.42 | 1.3 | 0.29 | 0.9 |
| June | 26.8 | 1,396 | 1.9 | 27.1 | 27.1 | 379 | 2.4 | 33.1 | 0.58 | 8.1 | 0.28 | 3.9 |
| July | 35.2 | 518 | 1.8 | 9.5 | 27.4 | 142 | 2.9 | 14.9 | 0.50 | 2.6 | 0.31 | 1.6 |
| Aug | 26.8 | 882 | 2.2 | 19.5 | 29.1 | 256 | 3.1 | 27.6 | 0.59 | 5.2 | 0.34 | 3.0 |
| Sept.§ | — | — | — | — | — | — | — | — | — | — | — | — |
| Oct | 41.1 | 374 | 2.1 | 7.9 | 24.2 | 91 | 3.2 | 11.8 | 0.56 | 2.1 | 0.26 | 1.0 |

*Results from plots 7, 8, and 9 are not included in the discussion on seasonal variations for, due to growth of a crop of hay on these plots, they are not comparable with the others.

†Cut for hay.

‡The monthly values for the check plot cannot be considered as reliable as those for the fertilized plots as they represent analyses of only one sample, while the others are averages of from three to five samples.

§No sample taken.

August and continuing into September, due no doubt to the copious rains of late August; and finally, in October, gradual cessation of growth and the dehydrating action of frost and sun are reflected in much the highest dry matter content of the season. Fig. 2 gives a graphical representation of these fluctuations and also visualizes sharply the consistently higher dry matter content of the grass from the check plot.

Contrasted with these values are those for average amount of dry matter produced per acre. In the case of the check plot, the latter are the reverse of the former all through the season, i.e., the lower dry matter content is always accompanied by the higher production, and the same is true for the fertilized plots, except during August and September.

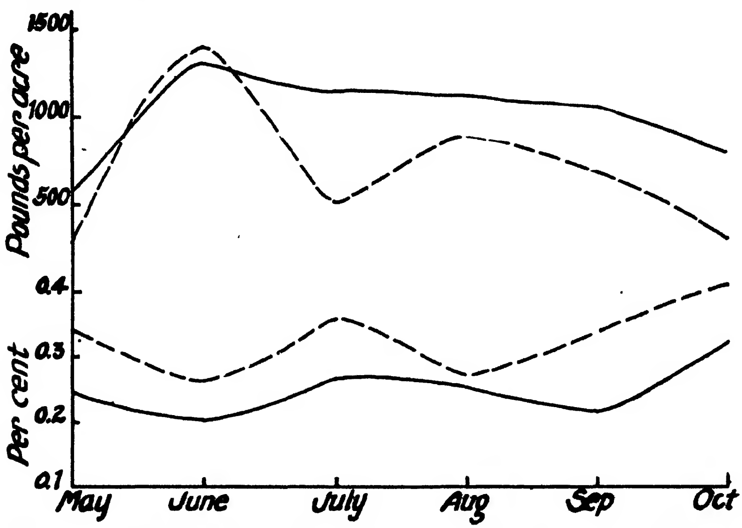


FIG. 2.—Average percentage and production of dry matter. The dotted line represents the check plot, the solid line the fertilized plots.

As shown in Fig. 2 the peak of dry matter production occurred in June in both fertilized and check plots coincident with the lowest percentage of dry matter. This graph also portrays the much more uniform production of dry matter throughout the season on the fertilized plots as compared with the check plot. Although the check plot reached a slightly higher point of production in June, its inability to withstand the less favorable conditions for growth during the midsummer period is strikingly evident.

## NITROGEN

The curve for nitrogen content[6] of the dry matter as depicted in Fig. 3 is of the same general contour in fertilized plots and check plot. The highest value is at the beginning of the season, dropping

[6]No sample having been taken from the check plot in September, the values shown for that month on the nitrogen and dry matter curves are interpolated. Because of the reasonable regularity of these curves for the other months it is felt that interpolation is justifiable.

rapidly through June to a minimum in July for the check plot, nearly to the minimum for the others; rising again quite rapidly through August and September and falling off abruptly in October in the fertilized plots, less so in the check plot. Except during the first month (May–June), the nitrogen content does not parallel the dry matter content. In fact, for the rest of the season it falls when the dry matter rises and *vice versa*. This latter condition is what would be expected, i.e., it is logical to suppose that the more succulent grass would contain a higher percentage of nitrogen in its dry matter due to its relatively higher ratio of protoplasm to supporting tissue. An explanation for the condition at the beginning of the season where high dry matter content is accompanied by high nitrogen content is not so readily forthcoming. If the relation did not hold true for the check plot as well as for the fertilized plots, the temptation would be to assign at least part of the high nitrogen value to the recent fertilizer

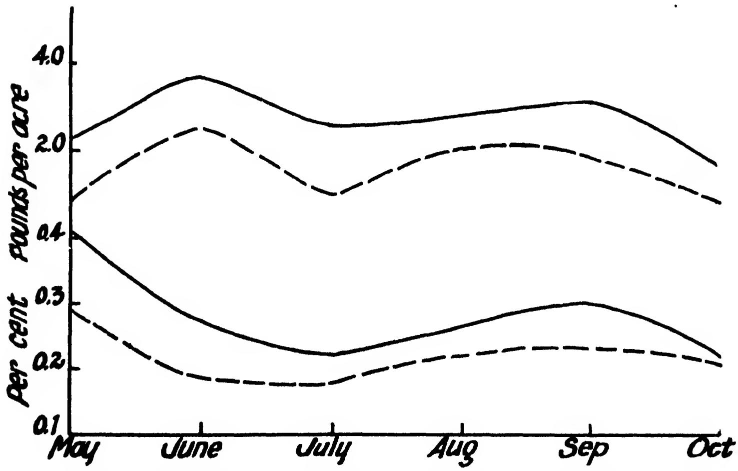


FIG. 3.—Average percentage and recovery of nitrogen. The dotted line represents the check plot, the solid line the fertilized plots.

treatment or to extraneous ammonia salts not yet washed into the soil, but under the circumstances this possibility is untenable. Possibly the tillering of the plants, which is characteristic of spring growth and is productive of an abundance of succulent young shoots with a high nitrogen content in their dry matter, accounts for it.

Except for the irregularity just discussed, the curve for average recovery of nitrogen per acre, as shown in Fig. 3, roughly parallels that for nitrogen content, and is of the same general contour in both check and fertilized plots. It also roughly resembles the curve for dry matter production (Fig. 2). The highest average recovery of nitrogen was in June and the lowest in October. Fig. 3 also shows clearly the consistently lower level of both nitrogen content and nitrogen recovery in the check plot. Because of the remarkable resemblance in contour of the nitrogen curves for check plot and fertilized plots, it may be concluded that in the case of this element seasonal factors

rather than fertilizer treatment control the fluctuations. Of these factors available moisture is probably the most important as evidenced by the rainfall curve in Fig. 1.

### CRUDE FIBER

The percentage of crude fiber[7] in the dried grass from the fertilized plots was lowest in May, rising quite sharply in June, and continuing to its maximum in July. Through August and September it declined quite uniformly but not markedly, and remained at about the same level in October as it reached in September. The situation is much

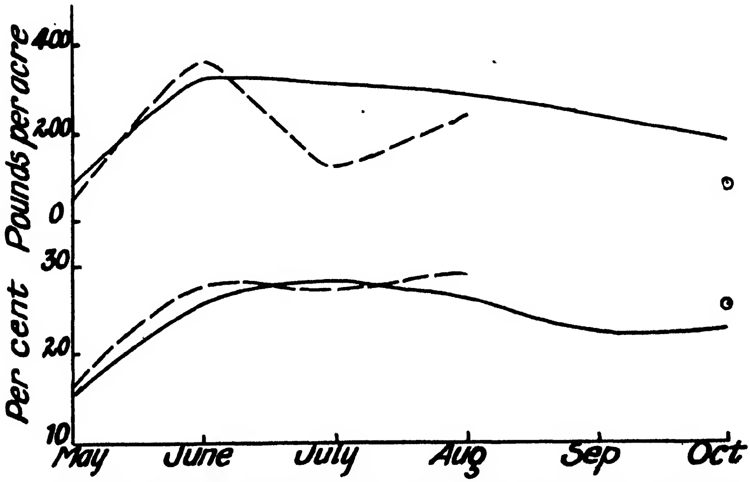


FIG. 4.—Average percentage and production of crude fiber. The dotted line represents the check plot, the solid line the fertilized plots.

the same for the check plot, except that it reached its maximum in August instead of in July. Except in July, its crude fiber percentage was higher throughout the season than that for the fertilized plots. The factors of most importance relative to these fluctuations in crude fiber are presumably the length of day and the intensity of the sun's rays, which control photosynthesis to a large extent. That plants elaborate fiber quite rapidly as they approach maturity is too well known to need mention. That the process is, in part at least, seasonal and to that extent independent of the stage of maturity of the plant is evidenced by these results. All samples were taken when the grass was quite immature and yet we note a fluctuation in fiber content of the dry matter from 16% in May to 28% in July. Part of the variation may have been due to slight differences in stage of maturity of the samples, but none had reached the "shooting"

[7]Because of the dissimilarity between the check plot curves and the fertilized plot curves for crude fiber, and also because of the irregularity in the check plot curves, it has not been thought wise to attempt to interpolate for this constituent values for the month of September when no sample was taken. The same is true for the curves for calcium and phosphorus. In Figs. 4, 5, and 6 the isolated point on the ordinate for October with a circle circumscribed about it represents the check plot value for that month.

stage. It seems advisable in view of the remarkable rise in fiber as midsummer approached to point out that although grass may be kept short by grazing or other means, it does not follow that it will have a composition and nutritive value throughout the season similar to that it had at the start.

Comparison of the curve for percentage of crude fiber (Fig. 4) with that for dry matter (Fig. 2) and for nitrogen (Fig. 3) shows that the fluctuations in fiber were more or less independent of those in dry matter and were quite strikingly the reverse of the variations in nitrogen.

The curves for acre production of fiber (Fig. 4) resemble very closely those for dry matter (Fig. 2). Maximum production was reached in June in both check and fertilized plots. In the latter it dropped off gradually and uniformly to the end of the season, while in the check plot it dropped abruptly in July and rose again in August. The fertilizer treatment seems to have smoothed out somewhat the crude fiber curves, but the seasonal variation remains quite marked.

### ETHER EXTRACT

The ether extract percentage and production resemble those for nitrogen, except that on the fertilized plots the maximum percentage and production is in August instead of earlier in the season; otherwise the similarity is marked. The high value for August is rather difficult of interpretation. It is perhaps due to a combination of an abundance of moisture and relatively high temperature, with a resultant high rate of general metabolism as well as of photosynthetic activity. The weather records bear out this supposition to some extent. The effect of an application of "Calurea" three weeks previously should also be taken into account here. As with nitrogen, the chief effect of the fertilizer seems to have been to maintain a higher level of production and a slightly higher percentage in the dry matter, the seasonal ups and downs being of about the same magnitude in the fertilized plots as in the check.

### CALCIUM

Except for a slight drop in June, the percentage of calcium in the herbage from the fertilized plots increased steadily and at a quite uniform rate throughout the season (Fig. 5). In the check plot this was not the case, the calcium content varying inversely as the dry matter in a manner similar to the nitrogen. That the fertilizer treatment smoothed out these seasonal irregularities in calcium content seems possible from a comparison of the two curves. This effect if due to the treatment is perhaps traceable to the application at three different times during the season of readily soluble calcium in the form of Calurea.

The curve for average recovery of calcium per acre (Fig. 5) has a similar contour in the case of the check plot to the curve for calcium content of the herbage, revealing definite seasonal irregularities. It also shows a striking resemblance to the curve for average production of dry matter (Fig. 2). In the case of the fertilized plots the similarity to the dry matter production curve is not so great, although it is still there. The main point of interest lies in the relative uniformity

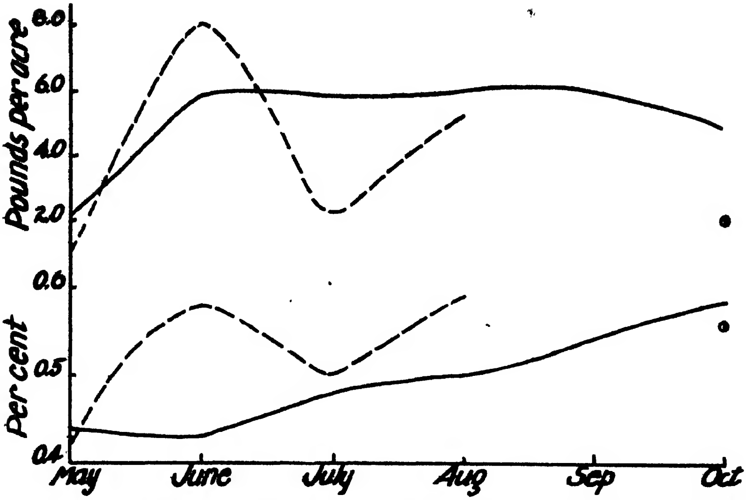


FIG. 5.—Average percentage and recovery of calcium. The dotted line represents the check plot, the solid line the fertilized plots.

of calcium production from June onwards on the fertilized plots. Attention has already been drawn to uniformity of production of dry matter on the fertilized plots as compared with the check plot. It is even more evident with calcium.

Taking into consideration the dissimilarity between the curves for check plot and for fertilized plots, and also the fact that the curve for calcium content of the herbage from the fertilized plots has no counterpart among any of the other curves plotted, the conclusion seems justifiable that in the case of this element the fertilizer treat-

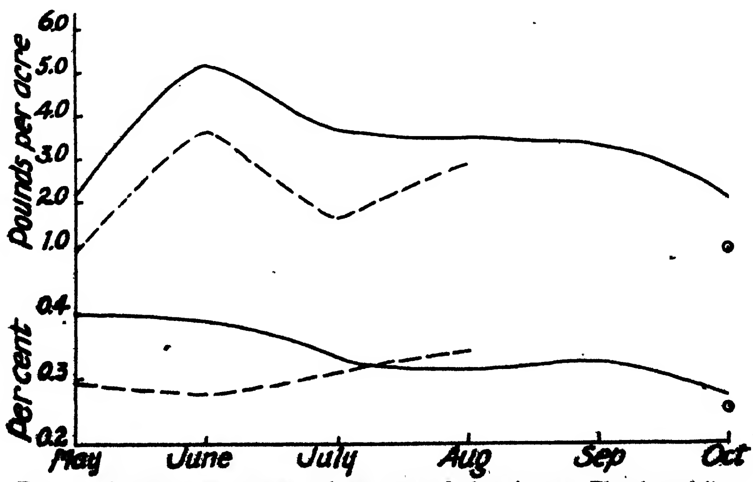


FIG. 6.—Average percentage and recovery of phosphorus. The dotted line represents the check plot, the solid line the fertilized plots.

ment tended to modify quite markedly any seasonal fluctuations in the calcium level.

### PHOSPHORUS

In the fertilized plots the situation with respect to phosphorus content of the grass is much the same as it is for nitrogen, there being a continual decrease from the beginning to the end of the season, except for a slight rise in the early autumn. The decline, however, is not nearly so rapid during the first half of the season as is the case with nitrogen (Fig. 6 compared with Fig. 3). The inexplicable feature of the results for phosphorus content is contained in those from the check plot. It would be reasonable to expect that they would parallel at least roughly the nitrogen curve for the check, with the higher value earlier in the season rather than in midsummer. As they are so at variance with the rest of the data, it would be unsafe to draw any conclusions from them until further results have been secured.

The curves for average recovery of phosphorus (Fig. 6 compared with Figs. 2 and 3) are quite similar to those for dry matter with a somewhat lesser resemblance to those for nitrogen, recovery being highest in June, dropping off rapidly in July, then somewhat more slowly until October when there is a decided decrease.

As with nitrogen, seasonal factors seem to have controlled the fluctuations, the chief effect of the fertilizer being to maintain a higher level of phosphorus recovery, due partly to a generally higher content of phosphorus in the dry matter and partly to a higher level of dry matter production.

### SUMMARY

Results of analysis of 44 samples of grass from nine 8-acre pasture plots fertilized and grazed intensively are reported and an interpretation is attempted. The fertilizer treatment consisted of a top-dressing of 55 pounds of nitrogen (N), 55 pounds of phosphoric acid ($P_2O_5$), and 67 pounds of potash ($K_2O$) per acre in the form of "Nitrophoska II" at the commencement of the growing season, followed at intervals throughout the season by three applications of 10 pounds each of nitrogen in the form of "Calurea." The plots were grazed in rotation and stocked with sufficient cattle to keep the grass quite short. Samples of the herbage were taken at the conclusion of the rest periods of the plots, just before the cattle were turned in. Dry matter, total nitrogen, crude fiber, ether extract, calcium, and phosphorus were determined.

The fertilizer treatment decreased considerably the percentage of dry matter in the grass, and decreased slightly the percentages of crude fiber and calcium in the dry matter. The percentage of nitrogen, phosphorus, and ether extract was increased, the nitrogen markedly so. Acre production of all constituents was increased, nitrogen being nearly doubled, while phosphorus and ether extract were increased by about one-half.

Inasmuch as these three constituents (nitrogen, phosphorus, and ether extract) are associated in the plant with compounds of a relatively high digestibility and nutritive value, and inasmuch as crude fiber constitutes the least digestible part of the plant, it may

safely be concluded from the data at hand that the fertilizer treatment increased the nutritive value of the dry matter of the grass.

Seasonal fluctuations in the content of the several constituents determined are not smoothed out to any great degree by the fertilizer treatment, except in the case of calcium which shows quite a uniform rate of increase in the fertilized plots as the season advances. Fluctuations in acre production, however, are somewhat reduced by the system, except in the case of nitrogen and ether extract which show much the same seasonal variations on the fertilized plots as on the check plot. With one exception, the peak of production on all plots and for all constituents occurred in June. Minimum production occurred in May in all cases. The exception noted was ether extract, maximum production of which occurred in August on the fertilized plots. As portrayed by the acre production curves, there is a quite close relation between production of total dry matter and of the other constituents.

Grass kept in the vegetative stage by grazing may be quite different in chemical composition in midsummer from what it was in the spring. The seasonal factors, rainfall, temperature, sunshine, and length of day, exert their influence irrespective of the stage of growth of the plant. Such evidence is partial justification for the common belief that in normal seasons pastures are at their best, qualitatively as well as quantitatively, in the spring and early summer. Further justification is found in the relatively high nitrogen, phosphorus, and ether extract content of the dry matter from these grasses in the month of May.

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# 13. THE ROLE OF PASTURE IN THE MINERAL NUTRITION OF FARM ANIMALS[1]

L. A. MAYNARD[2]

The adequate mineral nutrition of farm animals depends upon a number of inter-related factors. In the first place, there must be a sufficient supply of those minerals required for the normal functioning of the body processes. In the second place, efficient mineral nutrition depends upon the existence of a proper ratio between certain elements, for example calcium and phosphorus. Then there is the assimilation factor, usually referred to as vitamin D, which makes for a more efficient assimilation of calcium and phosphorus. Finally, there is the question of the harmful effect of certain elements when present in excessive amounts in the ration.

With all of these factors pasture is concerned, and the question of mineral nutrition on pasture is of major importance in view of the fact that over long periods pasture grass is the sole feed, particularly for certain species, in contrast to the conditions found in dry lot or in stable feeding where the ration consists of several feeds and where a deficiency of a certain element in one feed may be balanced by an excess in another. In view of this fact it is not surprising to note that the lack of adequate mineral nutrition first came to the attention of stockmen through observations on pasture and that the most extreme cases of malnutrition and disease which have been recorded as due to mineral deficiencies are those which have been observed on pasture.

## OBSERVATIONS ON MINERAL TROUBLES ON PASTURE

Beginning with the middle of the last century one finds in the animal husbandry literature reports from many parts of the world of studies of diseases of grazing animals occurring on certain areas and not occurring on other areas, and these reports indicate that these troubles had actually been noted much earlier. The troubles have been reported under a variety of names, such as osteomalacia, pica, and several local terms, but the symptoms had much in common—lameness, bone weakness, emaciation, and depraved appetite, especially a craving for bones or earthy material. Large death losses over widespread areas are recorded.

That inadequate mineral nutrition was involved in the development of the troubles was evidently recognized in Germany as early as 1859. Von Gohren (1)[3] reports that in that year in an area near the Rhine a disease was widespread which was characterized by brittle bones. He states that it was apparently the result of a lack of minerals in the fodder due to an unusually dry season and he refers to the use of bonemeal as a cure. Later, Grouven (2) analyzed the crops from areas where bone weakness was exhibited by the animals

[1]Paper read as part of the symposium on "Pasture Management Research" presented at the joint session of the New England Section of the Society and Section O of the A. A. A. S. held in New York City, December 28, 1928.

[2]Professor of Animal Husbandry, Cornell University, Ithaca, N. Y.

[3]Reference by number is to "Literature Cited," p. 706.

and also from areas where the trouble was not evident and found the crops from the former to contain only about half as much phosphorus as from the latter. Nessler (3) studied soils of the two areas and correlated the trouble with the nature of the underlying rocks. He showed the bone of affected animals to be much lower in ash than was the case for the normal animals, and he considered the trouble to be due to a lack of calcium phosphate in the feed. In a recent report König and Karst (4) have reviewed a large number of studies of the trouble in Germany and elsewhere and have reported studies of their own showing the influence of the mineral relations in the soil and of fertilization upon the minerals in the crops and upon the incidence of the disease.

These troubles caused by mineral deficiencies have been reported from many parts of the world. In 1899, Elliott (5) reported osteomalacia as occurring in horses in certain districts in Hawaii and not in others. In 1908, Ingle (6) reported a nutritional disease in South Africa as due to a high phosphorus and low calcium content of the herbage. Tuff (7) has described the history of the occurrence of osteomalacia in various areas in Norway and its cure by moving the animals to other areas or by feeding bonemeal.

The most striking case of deficient mineral nutrition in grazing animals has been reported by Theiler, Green, and du Toit (8) in South Africa where on widespread areas very high death losses result from a deficiency of phosphorus. In these areas the soil, and consequently the herbage, is so low in phosphorus as to result in a very subnormal rate of growth, in a low breeding efficiency, and in a marked decrease in milk yield. There results a craving for bones, and many animals die from infection as a result of eating decaying bones. The feeding of bonemeal entirely corrects the trouble.

These mineral deficiency troubles characterized by depraved appetite have been reported from several areas in the United States, including range cattle in Montana (9) and Texas (10) and in dairy cattle in Minnesota (11), Wisconsin (12), and Michigan (13). In each report large losses to the livestock industry are recorded. The reports from Minnesota and Wisconsin point clearly to a phosphorus deficiency in the soil and crops as a cause of the trouble. Legumes grow readily in the affected areas and the forage is, in general, high in calcium, but low in phosphorus. The analytical figures cited show an improper balance between calcium and phosphorus as well as a deficiency of the latter. The data from Michigan also indicate the trouble to be due to a lack of phosphorus. In all of the foregoing reports the studies show that the feeding of bonemeal is a successful preventive or corrective measure.

In contrast to these poor areas in the United States there are other areas, such as the bluegrass section of Kentucky and the limestone areas of southwestern Wisconsin and of Virginia, which are renowned for their capacity for growing and fattening livestock.

That iron starvation occurs in ruminants on pastures throughout wide areas in New Zealand has been established by the investigations of Aston (14) extending over a period of 25 years. In these areas

legumes grow readily and there is no evidence of calcium and phosphorus deficiency. The bones of the animals are normal. However, the grass is very low in iron compared to that of areas where the animals remain healthy and the affected animals are anemic. The feeding of iron salts corrects the trouble.

The occurrence of goitre in farm animals involving large losses in various areas due to a lack of iodine in the soil, water, and crops is now a well-recognized fact, but from the standpoint of pasture iodine presents no practical problem because the proper way to correct the deficiency is through the feeding of iodides.

Magnesium is an element that requires consideration from the standpoint that an excess of it may cause a loss of calcium from the body and thus interfere with bone formation. However, the practical significance with grazing animals requires further study. Some studies recently reported by Palmer, Eckles, and Schutte (15) dealing with the phosphorus deficiency trouble in Minnesota previously referred to indicate that where phosphorus is low a high intake of magnesium may aggravate the trouble by causing a loss of calcium from the body.

It is possible that certain of the rarer elements, such as manganese and copper, which have recently been found to be so deficient in certain soils as to affect adveresly the crops grown thereon, may also be limiting factors in the nutrition of animals. It is now known that both manganese and copper assist hemoglobin formation in anemia. In a recent report by Aston (14, 1928) regarding the iron deficiency troubles previously mentioned, it is stated that in the only area where the animals remain healthy despite a low iron content in the herbage, manganese is present in abnormally large amounts, and it is suggested that the animals remain healthy because the manganese aids in the utilization of the small amount of iron.

The question as to whether fluorine, an element which is needed by the animal in minute amounts but which is very toxic at larger intakes, is present in excess in certain herbage may merit study.

## SYSTEMATIC CHEMICAL STUDIES OF PASTURE GRASS

In the papers thus far reviewed it has been seen that certain studies were made of the mineral content of the soil and herbage in the affected area. The results obtained led in turn to systematic studies by agronomists of the mineral content of pasture grass and of the factors concerned in the variations found. In 1907, Armstrong (16) reported a study of 20 different English pastures on both hill and valley land, involving both clay and loam soils. The herbage on good grazing lands was found twice as rich in phosphorus and nitrogen as that on poor lands, the differences being correlated with the relative amounts of white clover present. A relation was also observed betwen the composition of the grass and the available soil phosphorus. In 1910, Forbes, Whittier, and Collison (17) reported analyses of 24 samples of Kentucky bluegrass taken from a variety of types of soils in Ohio and Kentucky, showing wide variations in calcium and phosphrous in the grass from different areas.

A series of investigations on the mineral content of pasture grass and its effect on herbivora has been carried out in Great Britain under the direction of a committee consisting of Elliott, Orr, and Wood and has been published in a series of papers. A paper by Godden (18) deals with the chemical analysis of samples of pasture grass from various areas. Cultivated, i. e., fertilized, pastures of England, Scotland, and Wales were found richer in nitrogen, calcium, phosphorus, potassium, and chlorine than natural hill pastures. On the hill pastures the samples were divided into "eaten" and "non-eaten" grass and the latter exhibited only 50 to 60% of the mineral content of the former but 16% more fiber. In passing from hill to lowland in the same locality there was a rise in the percentage of calcium, phosphorus, sodium, and nitrogen, and lowering of the fiber. In summarizing the results Godden points out that the various comparisons of the good and poor pastures showed little differences as regards calorie content, and that the poor pastures were always more deficient in minerals than in nitrogen. He also states that the highest mortality in sheep and the lowest grazing capacity were found on the pastures low in minerals and that whenever sheep have a choice they choose a grass high in minerals.

As a part of this general investigation of pasture grass carried out under the direction of the British Committee seasonal variations were studied and have been reported by Cruickshank (19). In studies of four pastures, two good and two inferior, it was found that the calcium rose to a maximum as the season advanced and then fell off gradually. The nitrogen followed the calcium but the range was less. The phosphorus and sodium tended to follow the calcium but rather irregularly. The range of variation was larger on the poorer pastures and the time when the maximum was reached varied in the different fields. The closer grazing on the better fields delayed the maturity of the grass and thus the time at which the percentages of the nutrients began to decline. No study of the changes in botanical composition was made.

A more extensive investigation of the seasonal variation of pasture grass has been reported by Woodman, Blunt, and Stewart (20). The first study was made of a reasonably good pasture on a light sandy soil—a neutral soil considered satisfactory as regards total and available potash and phosphoric acid. The grass, consisting mostly of creeping bent, was mowed every week. As the season advanced the calcium rose with an increase in white clover, but the phosphorus did not rise. At midseason there was a falling off in protein content and a rise in fiber, and these changes were most pronounced when the weather and botanical composition were unfavorable to the production of new grass. Toward the end of the season the calcium fell despite a rise in nitrogen. A significant observation was that the ratio of calcium to phosphorus was 2.11:1 in midsummer, too wide for optimum utilization of these minerals by the animal, as shown by the fact that sheep were in negative calcium balance at this time, while this negative balance did not occur in spring and autumn when the ratio was near 1:1.

In their second investigation Woodman and co-workers studied the grass on a heavy clay soil. The grass contained less clover than that studied in the first investigation, but due to a more copious and a better distributed rainfall, there was no striking zenith and falling off in growth. The calcium rose to a midseason maximum, but the rise was small compared to that observed in the first investigation. The phosphorus did not change. Due to the smaller amount of white clover present, the general level of calcium was lower than in the first experiment despite more calcium in the soil. The authors state that changes in botanical composition, any factors affecting seasonal productivity, and the nature of the grazing all contribute to the seasonal variations in mineral content. It is also stated that irrespective of botanical composition there need be no serious falling off in nutritive value in midseason in a closely grazed pasture where the soil, herbage, and weather conditions combine to cause continuous active growth.

While these experiments of Woodman and co-workers show that botanical composition is the most important factor governing the changes in mineral content, there are other studies which show that these changes occur even with the same species. For example, Fagan and Jones (21) have shown that there is a seasonal variation in phosphorus content for the same species when analyzed monthly throughout the season. Also, it should be borne in mind that a pasture rich in legumes does not necessarily indicate a feed providing optimum mineral nutrition, since some of the studies reviewed have shown that such a pasture may be very deficient in phosphorus or iron and may have an improper calcium-phosphorus ratio.

## INFLUENCE OF FERTILIZATION ON MINERAL CONTENT OF PASTURE GRASS

The studies showing correlations between the mineral content of the soil and of pasture grass led naturally to studies of the effect of fertilizers. As early as 1869 Roloff (22), in connection with his studies of the troubles in grazing animals occurring in certain areas of Germany, succeeded in doubling the calcium and phosphorus content of meadow grass by the use of fertilizers. Forbes and co-workers (17) have reported plat experiments with bluegrass differently fertilized with phosphates, potash, and lime showing the effect of the fertilizers to be generally direct and consistent. Barnes (23) found an increase in calcium and phosphorus in the grass by the application of superphosphate and lime to pasture, the increase depending upon the amount and type of clovers present. However, that the mineral content of the same species varies according to the fertility of the soil is indicated by an earlier report of Buckner (24) showing that crab grass in a limestone soil contained 44% more calcium and 22.7% more phosphorus than in an acid soil.

In connection with the reports of the striking mineral deficiency troubles found in grazing animals on certain areas it should be noted that Theiler and associates (8) report that the phosphorus content of the grass was tripled by manuring with superphosphate, that

Eckles and co-workers (11) report the beneficial effect of the application of phosphate in the affected area in Minnesota, and that Aston (14, 1928) reports the iron content of grass increased by manuring. Murphy (25) reports that in certain pasture areas of the Morningstar Peninsula, where bone troubles are common, healthy livestock can be maintained after fertilization.

As a part of the extensive investigations carried out under the direction of the British Committee, previously referred to, Godden (26) reports that the liming of a temporary pasture increased the percentages of calcium and nitrogen in the grass. On a moorland pasture a similar effect was noted from the application of lime, while the application of potash tended to depress the calcium in the grass. Godden concludes that the application of artificial fertilizers to grassland results in considerable modification of the mineral content of the grass, that calcium and phosphorus are most affected, and that calcium and nitrogen rise together.

The observation of von Fellenberg (27) and others that the iodine content of grass can be increased by iodine manuring has a certain practical significance in goitre areas in view of the fact that certain nitrates and phosphates are rich in iodine.

## IMPORTANCE OF MINERAL NUTRITION IN PASTURE STUDIES AND IN PASTURE IMPROVEMENT

The work here reviewed clearly indicates that the troubles in grazing animals resulting from inadequate mineral nutrition can be prevented by building up the mineral content of the grass through fertilization and by certain other procedures involved in pasture management. However, the studies reported have also indicated that the bad effects of these deficiencies can be overcome by supplementing the pasture with feeds rich in the needed minerals or with mineral supplements. The question arises, therefore, as to the extent to which the mineral content deserves consideration in pasture investigations and in any program for pasture improvement. From an economic standpoint it seems clear that, were mineral content the only consideration, the lacking minerals should be fed directly to the animals rather than to the plants. But where fertilization is under consideration from the standpoint of increasing the yield of pasture grass, the fact that mineral deficiencies can thus be made good also constitutes another point in favor of the practice. Other things being equal, the stockmen would naturally prefer a pasture adequate in minerals to avoid the cost and labor involved in feeding a mineral supplement.

It is especially important that animals receive an adequate supply of calcium and phosphorus during the pasture season. These minerals are most efficiently assimilated at this time because pasture grass contains the specific factor aiding in their assimilation and because of the beneficial effect of sunlight in this connection. It should be noted, however, that this effect of sunlight has not been demonstrated with dairy cows. That the calcium and phosphorus of mineral supplements are best utilized by dairy cows when fed in

connection with pasture grass is indicated by the studies of Hart and co-workers (28). Earlier studies by Hart and co-workers (29) with goats and by Forbes (30) with cows have shown that the calcium of green feed is better assimilated than the calcium of dry feed. Whether a pasture grass rich in calcium and phosphorus has any advantage, from the standpoint of assimilation, over a pasture grass poor in these elements but supplemented with calcium and phosphorus carriers is unknown.

Irrespective of the question as to whether it is practicable to increase the mineral content of pasture grass where it is deficient, it is important from the standpoint of animal husbandry that future pasture investigations should give increased consideration to the question of their mineral content. The stockman cannot tell whether he should feed a mineral supplement, nor can he select it intelligently, unless he knows the mineral content of the rest of his ration. This information is available for concentrates and dry roughages, although it is recognized that figures for the latter will vary somewhat according to the soil on which they are grown. The needed information is not available for pasture. Of course, it can never be as definite as for the dry feeds because of the many factors which influence the mineral content of pasture grass. However, systematic studies of the mineral content of pasture in various areas and under various conditions will certainly provide information useful to the animal industry in the areas concerned.

The previously described mineral deficiency troubles of grazing animals in certain areas have been noted under conditions where the symptoms were so striking and the losses so large as to force them to the attention of stockmen and investigators. However, experiments have shown that farm animals suffer from a lack of minerals without showing these striking symptoms since the latter are the cumulative results of long-time or severe deficiencies. The question of the state of the mineral nutrition of grazing animals on pastures where these extreme, easily recognized symptons have not been observed has been little studied and its investigation would seem an important part of the general pasture problem.

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## DISCUSSION

The earlier part of this symposium has dealt in large measure with the problem of increasing the productivity of pastures, in other words, quantity production. It is fitting that the last two papers should deal more particularly with quality production as revealed by chemical analysis of the grass produced. The importance of the mineral content of feeds has been receiving deserved attention during recent years and the minerals supplied by pasture have a direct bearing on the question of grain supplements and mineral supplements. This opens up the question as to whether, under usual conditions, it is advisable to feed mineral supplements to animals, or if satisfactory results may be obtained by fertilizing the soil to increase the mineral content of plants and supply animal needs in that way.

The first of these two papers also shows how yields have been increased by the Hohenheim system of grassland management. The question naturally arises as to whether or not the increased production is sufficient to pay for the extra labor and increased overhead in addition to the cost of fertilizers. At any rate, such a system does not seem to be adapted to the rough hill pastures so common in Vermont. But these hill pastures, like many in other states, do need improving both as to quantity and quality of yield. Of course proper fertilization may increase the nitrogen and mineral content of plants thus improving their quality. But if we are to attempt to effect this type of improvement in quality, we must first find out more about the natural mineral content of pasture grasses as pointed out in the last paper and which may be illustrated by a partial summary of results obtained in some Vermont pasture studies.

Maynard also pointed out that there should be an optimum ratio between the percentages of the different minerals, particularly calcium and phosphorus, and that this ratio should probably be less than 2 to 1. Table 1 gives the average percentage composition on a dry matter basis of the samplings from each of six different pastures. Samples were taken of the grass at the stage of growth as eaten by the cow and at approximately one month intervals throughout the season from late May to the middle of October.

TABLE 1.—*Average composition on dry matter basis of samplings from six Vermont pastures.*

| Pasture No. | Total ash | N | Cellulose | N-free extract | Ether extract | Ca | P |
|---|---|---|---|---|---|---|---|
| | % | % | % | % | % | % | % |
| 1 | 11.33 | 2.77 | 16.68 | 51.88 | 2.75 | 0.94 | 0.23 |
| 2 | 9.79 | 3.53 | 15.67 | 49.26 | 3.19 | 0.77 | 0.23 |
| 3 | 9.20 | 2.13 | 21.35 | 53.27 | 2.81 | 0.71 | 0.22 |
| 4 | 8.84 | 3.11 | 17.27 | 51.26 | 3.21 | 1.02 | 0.30 |
| 5 | 10.21 | 3.01 | 16.96 | 50.84 | 3.19 | 1.06 | 0.25 |
| 6 | 8.70 | 3.34 | 17.07 | 49.73 | 3.61 | 0.74 | 0.35 |

This shows that certain pastures produce grass having a calcium-phosphorus ratio of more than 4:1. Does this mean that care must be exercised not to increase the calcium content by the use of fertilizers? How about increasing the proportion of white clover growth and thus increasing the percentage of calcium? Or were these pastures specially deficient in phosphorus? If so, how might the phosphorus content be increased without a corresponding increase in calcium?

Archibald attributes the higher calcium content of grass from his plats 7, 8, and 9 to the greater amount of calcium added in the fertilizer and later explains the higher nitrogen content of this same grass by stating that these plats represented a more recent seeding and, therefore, probably grew a greater proportion of clover. May not this latter reason instead of the fertilizer account for the higher calcium content? Also, may not the growth following the cutting of a

crop of hay be normally different from that on plats pastured from early in the season?

Another set of Vermont trials with plats in 11 pastures from 6 of which records were obtained for two years, making a total of 17 records, showed total yields for the season as follows:

| | Green weight per acre, pounds | Dry matter per acre, pounds |
|---|---|---|
| Lowest | 848 | 320 |
| Highest | 20,336 | 4,031 |
| Average of 17 records | 7,807 | 2,093 |

The average dry matter composition of the 17 trials was as follows: Total ash, 11.89%; N, 3.06%; cellulose 19.09%; N-free extract, 46.61%; ether extract, 3.21%; Ca, 0.798%; and P, 0.268%. Here we find 3 parts of calcium to 1 of phosphorus.

Both Archibald and Maynard have referred to seasonal variations in nitrogen, calcium, and phosphorus. The Massachusetts trials showed considerable variation throughout the season. In 21 Vermont trials, including 12 different pastures and three different years from late in May to the middle of October, the percentage of nitrogen showed remarkable uniformity as follows: 2.80, 2.70, 2.82, 2.81, 2.76, and 2.85. These samples were taken while the grass was being constantly pastured so as to show as nearly as possible what the cows were eating, while the Massachusetts plats were sampled at the close of the "rest" periods, at which time the grass was doubtless longer and more mature than on our closely grazed Vermont pastures. Again, under close grazing conditions, the samples were all short, fresh growth grass quite uniform throughout the season except in quantity, while the Massachusetts plats, because of the "rest" periods, may have showed greater variation in stage of growth.

The seasonal variations in calcium and phosphorus from the six Vermont pastures first referred to showed first an increase and then a decrease as the season advanced similar to the results of Cruickshank referred to in both of the preceding papers. The range in percentage of dry matter was as follows:

| Calcium | Phosphorus |
|---|---|
| 0.72 | 0.25 |
| 1.01 | 0.28 |
| 1.02 | 0.28 |
| 0.78 | 0.24 |
| 0.74 | 0.22 |

This differs somewhat from the results obtained on the Massachusetts plats.

Maynard very properly states that it is desirable that mineral needs of farm animals should be met where possible by an appropriate make-up of the ration from the usual feeds without recourse to mineral supplements, and that it is desirable that pasture grass be sufficiently rich in the essential minerals so as to require no supplement. He also observes that the assimilation of calcium supplements is more efficient when fed with pasture grass than with dry feed. Four trials at the Vermont Station did not show increased assimilation when the silage in the rations was replaced with freshly cut short grass clippings. The question arises as to whether the wholesale advice given during recent years to feed mineral supplements with pasture is always correct.

It seems desirable, therefore, that pasture projects should be planned to include quality as well as quantity studies and that mineral analysis should be made. There also seems to be a need for studies planned to determine the assimilation of minerals from pasture grasses and from supplements when fed with pasture grass of varying composition.—H. B. Ellenberger, *Vermont College of Agriculture.*

# AGRONOMIC AFFAIRS

## THE IMPERIAL BUREAU OF SOIL SCIENCE

The Imperial Bureau of Soil Science, one of the eight bureaus, the formation of which was recommended by the Imperial Agricultural Research Conference of 1927, commenced work on May 1 at the Rothamsted Experimental Station. Sir John Russell, Director of Rothamsted, is also the Director of the Bureau, and Dr. A. F. Joseph, lately Sudan Government Chemist, has been appointed Deputy Director. The functions of the Bureau include the collection and distribution of all research work of importance on soils to the British Empire, the assistance of research workers in the prosecution of their investigations in whatever ways it can, the bringing together of workers from different parts of the Empire (either bv correspondence or in conference) interested in the same subjects, and to supply information generally which may facilitate the work of soil experts in the development of agriculture.

It is hoped that before long the Bureau will be in close touch with all soil investigators of the Empire, both at home and abroad, and that by means of information-circulars and other methods, the results of studies carried on in one part of the Empire will be made available for all. Arrangements will also be made to supply information dealing with soil investigations in foreign countries, the results of which (owing to language or other difficulties) are not readily available.

## ANNUAL MEETING OF SOCIETY

In a preliminary announcement of the annual meeting of the Society from the office of the Secretary it is stated that the meeting will be held November 14 and 15 at the Stevens Hotel in Chicago.

## MEETING OF WESTERN BRANCH OF SOCIETY

The Western Branch of the Society will hold its thirteenth annual meeting on July 15, 16, and 17 at the University of Idaho at Moscow and at the Washington State College at Pullman. The time will be divided evenly between the two institutions.

# A CORRECTION

On page 86 of the current volume of the JOURNAL, in an article by Dr. P. B. Kennedy on "Proliferation in *Poa bulbosa*," the last line of the legend to Fig. 2 should refer to parts 10–13 of the illustration and not to part 14 as stated in the legend.

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# OCCURRENCE OF "LINTLESS" COTTON PLANTS AND THE INHERITANCE OF THE CHARACTER "LINTLESS"[1]

FRED GRIFFEE and L. L. LIGON[2]

## INTRODUCTION

Occasionally cotton plants are found which have smooth seeds and practically no lint. Cotton growers do not harvest seed from these plants since they consider them degenerates and their presence an indication of "running out" of the seed. The "lintless" plants appear in varieties possessing normally linted and fuzzy seeds. There is some variation in the lintless plants in the amount of lint developed even on one plant. The later bolls tend to have more lint than the early bolls, but none have more lint than just enough to hold the seeds together when extracted from the boll. Since the smooth condition of the seed has been found by a number of workers[3] to behave as a dominant or partially dominant character, the appearance of these plants was thought to be of some interest from the standpoint of heredity. Particularly since mutations from recessiveness to dominance are less frequent than changes in the opposite direction. Accordingly, a few seeds were obtained of lintless plants in the fall of 1925 and plants were grown in 1926, all of which came from seeds without lint or fuzz. A few crosses were made with a red-center King strain having normally linted and fuzzy seeds.

[1]Contribution from the Department of Field Crops and Soils, Oklahoma Agricultural Experiment Station, Stillwater, Okla. Published with the approval of the Director of the Station. Received for publication February 8, 1929.

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[3]HAYES, H. K., and GARBER, R. J. Breeding Crop Plants. New York: McGraw-Hill Book Company. 1927.

## EXPERIMENTAL RESULTS

The plants grown in 1926 from lintless seeds were of two types, one of which had lint while the other was lintless. From this it is apparent that the smooth seed characteristic is dominant to the fuzzy condition. Fourteen linted-smooth and 12 lintless plants were continued in 1927, together with the few crosses of Lintless x King.

The first part of Table 1 contains the data from the linted-smooth plants. The observed numbers suggest a 1:2:1 ratio of linted fuzzy: linted smooth: lintless, which would be obtained on the basis of a single factor difference between lintless and normal linted-fuzzy

*: in the study of the character "lintless," 1927.*

| Row No., 1927 | Plant No., 1926 | Linted-fuzzy | Frequency of types: Linted-smooth | Lintless | Total | Assumed mother parent genotype |
|---|---|---|---|---|---|---|
| 91 | 1 | 10 | 18 | 4 | 32 | Ll |
| 102 | | 15 | 22 | 6 | 43 | Ll |
| 103 | | 10 | 16 | 18 | 44 | Ll |
| 105 | | 13 | 21 | 3 | 37 | Ll |
| 109 | | 3 | 13 | 7 | 23 | Ll |
| 110 | | 13 | 20 | 9 | 42 | Ll |
| 111 | | 10 | 24 | 13 | 47 | Ll |
| 112 | 21 | 12 | 26 | 15 | 53 | Ll |
| 115 | | 18 | 41 | 20 | 59 | Ll |
| 117 | | 12 | 36 | 9 | 57 | Ll |
| 121 | | 14 | 16 | 10 | 40 | Ll |
| 122 | | 13 | 31 | 8 | 52 | Ll |
| 124 | | 13 | 25 | 9 | 47 | Ll |
| 126 | | 17 | 43 | 14 | 74 | Ll |
| Total observed | | 173 | 352 | 145 | 670 | |
| Calculated on 1:2:1 basis | | 167.5 | 335 | 167.5 | 670 | |
| | | $X^2=4.0657$ | $P=0.1318$ | | | |
| Calculated on basis 19.35% natural crossing | | 183 | 335 | 152 | 670 | |
| | | $X^2=1.7315$ | $P=0.4320$ | | | |
| 104 | | | 4 | 23 | 27 | LL |
| 106 | | | 7 | 33 | 40 | LL |
| 107 | | | 18 | 39 | 57 | LL |
| 116 | | | 18 | 22 | 40 | LL |
| 118 | | | 4 | 16 | 20 | LL |
| 119 | | | 3 | 22 | 25 | LL |
| 120 | | | 10 | 45 | 55 | LL |
| 123 | | | 19 | 17 | 36 | LL |
| 125 | 34 | | 17 | 20 | 37 | LL |
| 113 | | | 5 | 47 | 52 | LL |
| 114 | | | 0 | 31 | 31 | LL |
| 127 | | | 7 | 37 | 44 | LL |
| Total | | | 112 | 352 | 464 | |

Percentage linted-smooth = 24.1

seeds, assuming L to be a factor for lintless and partially dominant to l the factor for linted-fuzzy seeds. The second part of Table 1 presents the data from the lintless plants which, according to the assumption above, should have been homozygous and therefore should have given only lintless plants on the assumption that they were self-pollinated. It is known, however, that cotton cross pollinates naturally to some extent, and this fact is taken into consideration in the analyses of these and succeeding data.

In an experiment to ascertain the frequency of cross pollination in cotton at Stillwater, the writers[4] found that crossing took place to the extent of 10% between rows 3.5 feet apart and 9% to the second row from a red-center King strain. It is logical to assume, therefore, that any single row receives at least 19% of its pollen from neighboring rows. If the plants for which data are given in the latter part of Table 1 were of the genotype LL, then the percentage of linted-smooth plants should indicate approximately the extent of natural crossing between rows planted 3.5 feet apart since the lintless row was flanked by cotton of the linted-fuzzy type. It may be assumed further that crossing between plants in the same row would take place with at least as great a frequency. If all the plants in a row are alike genotypically, this latter possibility need not be considered, but in this case it is very evident that plants in the row were not alike. It is possible, for instance, that some of the pollen grains from the lintless row were carriers of the factor l.

The percentage of linted-smooth plants obtained from the linted-smooth parent plants (latter part Table 1) represents a combination of the percentages of natural crossing between rows and that of crossing within the row. By taking this 24.1% as the basis for calculation, it is estimated that 19.5% natural crossing took place from

TABLE 2.—*Behavior of the lintless parents and the first generation plants in a cross of lintless x King, 1927.**

| Parents | 1926 plant | 1927 row | Linted-fuzzy | Linted-smooth | Lintless | Total | Assumed mother parent genotype |
|---|---|---|---|---|---|---|---|
| Lintless | 34 | 125 | | 17 | 20 | 37 | LLrr |
| Lintless....... | 1 | 91 | 10 | 18 | 4 | 32 | Llrr |
| Lintless....... | 21 | 112 | 12 | 26 | 15 | 53 | Llrr |
| 34 x King, $F_1$... | 34 | 14 | 0 | 7 | 0 | 7 | LLrr |
| 1 x King, $F_1$... | 1 | 15 | 1 | 3 | 0 | 4 | Llrr |
| 21 x King, $F_1$... | 21 | 16 | 9 | 10 | 0 | 19 | Llrr |

*All $F_1$ plants had red centers.

[4]LIGON, L. L., and GRIFFEE, FRED. Unpublished data on natural crossing in cotton.

the neighboring rows and the same amount between plants within the lintless row. Admittedly there is a possibility of error in assuming that the natural crossing from these two sources is equal. Since the data agree with this assumption, however, there is some basis in fact. The data for the breeding behavior of the parent plants of the crosses lintless x King and the $F_1$ generation of the crosses are given in Table 2.

The genotype of plant 34 is given as LLrr, and since King is llRR, all plants in row 14 are linted-smooth. Plants 1 and 21 are assumed to be of the genotype Llrr as the results agree with those obtained from backcrossing a heterozygote to the recessive, row 16 particularly having 9 linted-fuzzy to 10 linted-smooth plants. There are three points to be made here in regard to the assumption that plant 34 was of the genotype LLrr and that plant 21 was of the genotype Llrr. First, the King parent was used as the pollen parent, and since the flowers of all $F_1$ plants had red centers, all received from King the factor for linted-fuzzy seeds. Second, plant 34 very likely did not carry the factor for linted-fuzzy seeds or its progeny when crossed with King would have shown some fuzzy-seeded plants. Third, plant 21 surely carried the factor for fuzzy seeds since approximately half of its progeny in the cross with King possessed fuzzy seeds. These facts all tend to support the hypothesis advanced as to the nature of the character lintless.

The hybrid plants were tested in 1928 for their breeding behavior and the data are given in Table 3. It may be noted that all $F_1$ linted-smooth plants gave progeny of three kinds, *viz.*, linted-fuzzy, linted-smooth, and lintless, and in numbers somewhat resembling a 1:2:1 ratio. When the same correction is made for natural crossing as was made above, the observed and calculated ratios are in very close agreement. The progenies from $F_1$ linted-fuzzy plants also are in agreement with the hypothesis.

Only one plant, 15-2, bred true for linted-fuzzy seeds. All other progenies contained some linted-smooth plants, and these could come only from natural crossing in the row the previous year since the hybrid plants in 1927 were flanked on both sides by linted-fuzzy types as was the case in 1926 with the lintless row. The 7.3% of linted-smooth plants in the progenies from linted-fuzzy $F_1$ plants suggests that possibly the natural crossing between plants in the row is somewhat higher than estimated, although the agreement with the calculated is reasonably good.

The data from the progenies of linted-smooth $F_1$ plants are given in Table 4 in such a manner that the relation may be observed be-

TABLE 3.—*Breeding behavior in the second generation of the cross lintless x King, 1928.*

| 1927 row and plant | 1928 row | Red center | White center | Linted-fuzzy | Linted-smooth | Lintless | Total number of plants | Assumed mother parent genotype |
|---|---|---|---|---|---|---|---|---|
| | | | Class frequencies in per cent | | | | | |
| | | | | Linted-smooth | | | | |
| 14–1 | 20 | 75.0 | 25.0 | 50.0 | 31.3 | 18.7 | 16 | LlRr |
| 2 | 21 | 84.0 | 16.0 | 28.0 | 72.0 | 0.0 | 25 | LlRr |
| 3 | 22 | 60.0 | 40.0 | 15.0 | 65.0 | 20.0 | 20 | LlRr |
| 4 | 23 | 62.5 | 37.5 | 25.0 | 37.5 | 37.5 | 8 | LlRr |
| 5 | 24 | 60.0 | 40.0 | 33.3 | 66.7 | 0.0 | 15 | LlRr |
| 6 | 25 | 73.3 | 26.7 | 60.0 | 13.3 | 26.7 | 15 | LlRr |
| 7 | 26 | 66.7 | 33.3 | 33.3 | 44.4 | 22.3 | 18 | LlRr |
| 15–1 | 27 | 63.2 | 36.8 | 31.6 | 42.1 | 26.3 | 19 | LlRr |
| 3 | 29 | 71.4 | 28.6 | 28.6 | 61.9 | 9.5 | 21 | LlRr |
| 4 | 30 | 68.4 | 31.6 | 60.5 | 23.7 | 15.8 | 38 | LlRr |
| 16–2 | 32 | 81.0 | 19.0 | 33.3 | 52.4 | 14.3 | 21 | LlRr |
| 5 | 35 | 70.0 | 30.0 | 22.5 | 50.0 | 27.5 | 40 | LlRr |
| 7 | 37 | 57.1 | 42.9 | 35.7 | 57.1 | 7.2 | 28 | LlRr |
| 10 | 40 | 76.0 | 24.0 | 20.0 | 48.0 | 32.0 | 25 | LlRr |
| 11 | 41 | 65.0 | 35.0 | 25.0 | 60.0 | 15.0 | 20 | LlRr |
| 15 | 45 | 77.8 | 22.2 | 38.1 | 36.5 | 25.4 | 63 | LlRr |
| 16 | 46 | 77.1 | 22.9 | 25.7 | 62.9 | 11.4 | 35 | LlRr |
| 19 | 49 | 76.2 | 23.8 | 61.9 | 31.0 | 7.1 | 42 | LlRr |
| Average | | 70.3 | 29.7 | 34.9 | 47.5 | 17.6 | Total 469 | |
| Calculated normal | | 75.0 | 25.0 | 25.0 | 50.0 | 25.0 | | |
| | | | $X^2=7.3608$ | $P=0.0259$ | | | | |
| Calculated on basis 19.35% natural crossing | | 70.2 | 29.8 | 32.3 | 50.0 | 17.7 | | |
| | | | $X^2=0.3349$ | P=Good fit | | | | |
| | | | | Linted-fuzzy | | | | |
| 15–2 | 28 | 56.2 | 43.8 | 100.0 | 0.0 | 0.0 | 16 | llRr |
| 16–1 | 31 | 63.9 | 36.1 | 94.4 | 5.6 | 0.0 | 72 | llRr |
| 4 | 34 | 66.7 | 33.3 | 93.3 | 6.7 | 0.0 | 30 | llRr |
| 6 | 36 | 66.7 | 33.3 | 88.9 | 11.1 | 0.0 | 18 | llRr |
| 8 | 38 | 87.5 | 12.5 | 68.8 | 31.2 | 0.0 | 16 | llRr |
| 9 | 39 | 71.6 | 28.4 | 98.5 | 1.5 | 0.0 | 67 | llRr |
| 13 | 43 | 76.7 | 23.3 | 96.7 | 3.3 | 0.0 | 60 | llRr |
| 14 | 44 | 66.7 | 33.3 | 92.6 | 7.4 | 0.0 | 27 | llRr |
| 17 | 47 | 56.9 | 43.1 | 96.6 | 3.4 | 0.0 | 58 | llRr |
| 18 | 48 | 69.8 | 30.2 | 97.7 | 2.3 | 0.0 | 43 | llRr |
| Average | | 68.3 | 31.7 | 92.7 | 7.3 | 0.0 | Total 407 | |
| Calculated on basis 19.35% natural crossing | | 70.2 | 29.8 | 95.2 | 4.8 | 0.0 | | |
| Deviation | | 1.9 | | | 2.5 | | | |
| Probable error | | 2.3 | | | 1.1 | | | |

tween the character pairs lintless vs. linted-fuzzy and red center of flower vs. white center. Without the correction for natural crossing, the observed and calculated relations are not at all in agreement. However, when correction is made on the basis of 19.35% natural crossing as before, the observed and calculated agree very well, P for the $X^2$ goodness of fit test being 0.4286. Apparently these two character pairs are inherited independently.

TABLE 4.—*Consideration of the character pair red center vs. white center in relation to linted-fuzzy vs. lintless in rows segregating for lintless, second generation of cross lintless x King, 1928.*

| 1927 row and plant | 1928 row | Red center Linted-fuzzy | Red center Linted-smooth | Red center Lintless | White center Linted-fuzzy | White center Linted-smooth | White center Lintless | Total | Assumed mother parent genotype |
|---|---|---|---|---|---|---|---|---|---|
| 14–1 | 20 | 6 | 3 | 3 | 2 | 2 | 0 | 16 | LlRr |
| 2 | 21 | 7 | 14 | 0 | 0 | 4 | 0 | 25 | LlRr |
| 3 | 22 | 1 | 9 | 2 | 2 | 4 | 2 | 20 | LlRr |
| 4 | 23 | 2 | 2 | 1 | 0 | 1 | 2 | 8 | LlRr |
| 5 | 24 | 3 | 6 | 0 | 2 | 4 | 0 | 15 | LlRr |
| 6 | 25 | 7 | 1 | 3 | 2 | 1 | 1 | 15 | LlRr |
| 7 | 26 | 4 | 6 | 2 | 2 | 2 | 2 | 18 | LlRr |
| 15–1 | 27 | 4 | 5 | 3 | 2 | 3 | 2 | 19 | LlRr |
| 3 | 29 | 3 | 10 | 2 | 3 | 3 | 0 | 21 | LlRr |
| 4 | 30 | 15 | 6 | 5 | 8 | 3 | 1 | 38 | LlRr |
| 16–2 | 32 | 6 | 8 | 3 | 1 | 3 | 0 | 21 | LlRr |
| 5 | 35 | 6 | 14 | 8 | 3 | 6 | 3 | 40 | LlRr |
| 7 | 37 | 6 | 9 | 1 | 4 | 7 | 1 | 28 | LlRr |
| 10 | 40 | 4 | 8 | 7 | 1 | 4 | 1 | 25 | LlRr |
| 11 | 41 | 4 | 6 | 3 | 1 | 6 | 0 | 20 | LlRr |
| 15 | 45 | 17 | 19 | 13 | 7 | 4 | 3 | 63 | LlRr |
| 16 | 46 | 6 | 17 | 4 | 3 | 5 | 0 | 35 | LlRr |
| 19 | 49 | 22 | 9 | 1 | 4 | 4 | 2 | 42 | LlRr |
| Total observed | | 123 | 152 | 61 | 47 | 66 | 20 | 469 | |
| Calculated on random sample basis | | 87.9 | 175.9 | 87.9 | 29.3 | 58.6 | 29.3 | 468.9 | |
| | | | | $X^2=40.0745$ | $P=0.000000$ | | | | |
| Calculated on basis 19.35% natural crossing | | 106.3 | 164.6 | 58.3 | 45.1 | 69.9 | 24.7 | 468.9 | |
| | | | | $X^2=4.9050$ | $P=0.4286$ | | | | |

## DISCUSSION

Taking all of the data into consideration, the results agree quite well with the assumption that the lintless characteristic is dependent

for its expression on a single factor which is partially dominant to the normal, the heterozygous condition being linted-smooth. It is worthy of note that no plants were obtained with fuzzy seeds and lacking lint. It may be observed also that the correction for natural crossing brings the observed and calculated ratios of plants with red-centered vs. white-centered flowers into close agreement. The appearance of the lintless character may be explained by assuming that the factor l mutated to L. The heterozygous plants ordinarily would remain unnoticed since they are normal so far as the development of lint is concerned. Since this study was begun several "lintless" plants have been observed in the variety Triumph, Oklahoma No. 44. The factor for lintless, while conditioning smooth seeds, must be a different factor than any other factor reported for smooth seeds, since in the homozygous condition it inhibits the development of lint as well. It might equally well be considered that the linted-fuzzy condition is partially dominant to lintless since the heterozygote is an intermediate.

## SUMMARY

1. Cotton plants were discovered which had smooth seeds and practically no lint. These plants are termed lintless.

2. The mode of inheritance of the lintless character was studied by means of progeny tests of lintless plants and hybrids between lintless and King, a variety with linted-fuzzy seeds and red-centered flowers.

3. Natural crossing is taken into consideration in the analysis of the results. It is estimated that natural crossing on a single row from neighboring rows takes place to the extent of 19.35% and that the same amount takes place between plants in the row.

4. The results indicate that the lintless character differs from linted-fuzzy by a single genetic factor and that this factor pair is inherited independently of the factor pair for petal spot vs. no petal spot.

5. The occurrence of the lintless character may be explained on the basis of mutation.

# BULKED-POPULATION METHOD OF HANDLING CEREAL HYBRIDS[1]

V. H. FLORELL[2]

In the improvement of the close-fertilized cereals by hybridization, the pure line or pedigree method is used most commonly. By this method the individual plants of the different families in each generation may be studied. Often after the $F_2$ generation only the individual plants of the best families in each generation are subjected to close scrutiny. Clearly the amount of material that may be carried in this way is limited by the time and funds at the disposal of the plant breeder. In the present extensive search for superior individuals it often is advantageous to grow a comparatively large number of combinations so as to increase the chances for obtaining superior types. In order to do this it becomes necessary to make use of some method which will economize the time of the worker and yet make reasonably certain that the desired plant material may be preserved for selection.

Such a method of handling was devised by Nilsson-Ehle and his associates at the Swedish Plant Breeding Station at Svalöf. The method was described by Newman (6)[3] in 1912. It consists essentially of the creation of populations by hybridization or crossing, growing these in bulk or "en masse" for six or eight generations, and then making hand selections for comparative testing. During the growing of the hybrid generations, artificial selection toward a definite type usually is practiced, thus eliminating weak and undesirable plants. At the end of this time individual plant selections are made and tested in the usual manner of conducting selection experiments.

The method described by Newman was further called to the attention of plant breeders by Babcock and Clausen (2) and later by Hayes and Garber (4) and by Bauer (3). The "population" method (1), or the "bulked-population" method, as it will be called in this paper, is used to some extent by plant breeders in the United States, and according to Dr. R. E. Clausen (verbal statement in 1928), it is being used extensively by commercial seedsmen in Germany and to some extent in other parts of Europe.

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[2]Associate Agronomist.

[3]Reference by number is to "Literature Cited," p. 724.

The object of this paper is to describe the course of a bulked-population experiment as conducted at University Farm, Davis, Calif., and to indicate from the results of such experiment the possibilities of this method of handling hybrid material.

## EXPERIMENTAL DATA

Hybrid material was grown first in bulk at Davis in 1923 when it became evident that the large number of wheat hybrids grown by the pedigree method could not be adequately cared for in this manner. Table 1 gives a list of the combinations or crosses grown in bulk from 1923 to 1926, with the number of head selections grown in 1927 and the number of strains first grown in a comparative replicated triple-row experiment in 1928. The locality where the populations were grown, the dates of seeding and harvest, and the area sown to each hybrid are given in the lower part of the table.

A total of 19 crosses was included in the experiments reported here. Each cross was designated by a number consisting of the last two numerals of the year when the cross was made and the series number of the cross, followed by the usual designation of the generation. Thus the identity and generation of the seed were indicated conveniently. It will be noted that more bulked populations were added from time to time. In most cases these were grown for one or more generations by the pedigree method. In such cases several of the best rows of each were harvested and threshed together to represent the cross.

To reduce the time required for the experiment, growing a so-called summer crop, as well as the normal winter crop, was attempted. The summer crop was sown in July or early August and harvested in late November; the winter crop was sown in January and harvested in June. This program of biannual cropping proved to be practicable. Successful summer crops were grown in preliminary experiments at Stanford University, Palo Alto, Calif., in the summers of 1923 and 1924. In 1925 a summer crop was sown at Stanford University, but due to the depredations of a band of sheep it was a failure. In the following seasons the summer crops were grown with success at University Farm, Davis. However, Palo Alto is a more favorable locality for summer cropping of spring-habit cereals because of its cooler summer temperatures. Average daily temperatures in July and August are about 10 degrees cooler at Palo Alto than at Davis.

In 1923 the area utilized for each cross was limited to a few rows in the nursery. In the remaining years of the experiment single fiftieth-acre and hundredth-acre plats, sown with the grain drill, were used for the winter sowing. In the summer sowing each cross was sown in triplicate 10-rod rows.

TABLE 1.—*Wheat hybrids grown biannually in bulked populations at University Farm, Davis, and at Stanford University, Palo Alto, Calif., in some or all of the crop years from 1923 to 1926.*

| Cross | 1923 Winter | 1923 Summer | 1924 Winter | 1924 Summer | 1925 Winter | 1926 Winter | 1927 Number head rows from selected heads* | 1928 Number of selections increase |
|---|---|---|---|---|---|---|---|---|
| Canberra x Pacific Bluestem | $21218F_2$ | | $21218F_3$ | | $21218F_4$ | $21218F_5$ | 17 | |
| Ruby x Canberra | $21220F_2$ | | $21220F_3$ | | $21220F_4$ | $21220F_5$ | 10 | |
| Hard Federation x Goldcoin | $20152F_3$ | | $20152F_4$ | | $20152F_5$ | $20152F_5$ | 36 | 1 |
| Hard Federation x Federation | | $21188F_3$ | $21188F_4$ | | $21188F_5$ | $21188F_6$ | 23 | 3 |
| White Federation x Federation | | | $21190F_3$ | $21190F_4$ | $21190F_5$ | $21190F_6$ | 47 | 5 |
| Bobs x Federation | | | $21192F_3$ | $21192F_4$ | $21192F_5$ | $21192F_6$ | 34 | 4 |
| Federation x Bunyip | | | $21195F_3$ | $21195F_4$ | $21195F_5$ | $21195F_6$ | 49 | 4 |
| Canberra x Federation | | | $21196F_3$ | $21196F_4$ | $21196F_5$ | $21196F_6$ | 26 | 2 |
| Hard Federation x Bunyip | | | $21199F_3$ | $21199F_4$ | $21199F_5$ | $21199F_6$ | 31 | 6 |
| Hard Federatoin x Dicklow | | | $21201F_3$ | $21201F_4$ | $21201F_5$ | $21201F_6$ | 28 | 3 |
| Hard Federation x Ruby | | | $21205F_3$ | $21205F_4$ | $21205F_5$ | $21205F_6$ | 11 | |
| Canberra x Hard Federation | | | $21207F_3$ | | $21207F_4$ | $21207F_5$ | 33 | 1 |
| Bunyip x White Federation | | | $21209F_3$ | $21209F_4$ | $21209F_5$ | $21209F_6$ | 39 | 7 |
| Marquis x Canberra | | | $21211F_3$ | | $21211F_4$ | $21211F_5$ | 27 | 4 |
| Dicklow x Bobs | | | $21215F_3$ | | $21215F_4$ | $21215F_5$ | 22 | |
| Bobs x Canberra | | | $21215F_3$ | | $21216F_4$ | $21216F_5$ | 13 | 1 |
| Oudebaard x Bobs | | | | $22245F_3$ | $22245F_4$ | $22245F_5$ | 9 | 2 |
| Marquis x Bobs | | | | | $21225F_4$ | $21225F_5$ | 19 | 2 |
| Bunyip x Canberra | | | | | $21226F_4$ | $21226F_5$ | 22 | |
| Location of planting | Davis | Palo Alto | Davis | Palo Alto | Davis | Davis | Davis | Davis |
| Date sown | 11/27/22 | 8/6/23 | 11/20/23 | 7/17/24 | Jan., 1925 | 12/14/26 | 11/10/26 | Nov., 1927 |
| Harvested | 6/15/23 | 11/27/23 | 6/10/24 | 11/30/24 | June, 1925 | Selected Aug., 1926 | June, 1927 | June, 1928 |
| Area sown to each hybrid | Duplicated 20-foot rows | Duplicated 25-foot rows | Fiftieth-acre plat | Three 10-rod rows | Fiftieth-acre plat | Hundredth-acre plat | 6-foot head rows | Three 1-rod rows, triplicated |

*Selected at Davis in 1926 for growing in head rows at Davis in 1927 and for increase in 1928.

Each year at harvest a certain amount of artificial selection was practiced, particularly in the later generations. Selection for type of plant, head, kernel, etc., was confined mostly to the winter crop, because plant growth and development in the summer crop is more or less abnormal. Selection for earliness was confined mainly to the summer crop. Differences in time of maturity of plants are increased in the summer-sown hybrids. Early maturing varieties and plants tend to develop and ripen quickly, while the later ones become delayed in maturity more and more as the daily temperatures and the length of day are reduced with the advance of the season. This accentuated spread in time of ripening facilitates selection and is important for the cereal breeder in a region where earliness is a highly desirable character.

Because of the relatively few character differences between the parents in most of the crosses which were carried as bulked populations, it was decided to make head selections from the 1926 crop for comparative testing. Ten of the crosses from which selections were made were in the $F_6$ generation and nine were in the $F_5$. Usually a winter crop is harvested in June but, in order to give opportunity for shattering, the ripe plants were left unharvested until August. Head selections of desirable types were then made. Plant selections would have provided a larger supply of seed, but with drilled grain it is difficult to separate individual plants and from the standpoint of purity this practice is questionable. The number of heads selected from each cross is listed in the column headed 1927 in Table 1. A total of 476 selections was made.

In November, 1926, the seeds from the selected heads were sown in 6-foot head rows. Fifty kernels from each head were spaced 1.5 inches apart in rows 1 foot apart. In 1927 only the best rows, selected on the basis of type of spike and resistance to lodging, shattering, diseases, etc., were harvested for the next year's experiment. These were put in a comparative experiment in 16-foot rows in 1928.

## YIELDS IN 1928

Each selection was sown in replicated (three times) triple rows. Hard Federation was used as a check variety after every fifth selection. The average yields of the Hard Federation check variety, based on location in the three series of plats, ranged from 33.7 to 40.5 bushels per acre. The average for all (33) check rows was 36.7 bushels per acre. The average yields of 33 of the 45 selections, or 73.3% of the total number, were above that of the check variety. The highest yield, 55.1 bushels, was obtained from a selection of White Federation x Federation and the second highest, 52.9 bushels per acre, from

Federation x Bunyip. The average yield of the Federation parent, also sown in triplicate triple rows, was 46.5 bushels per acre.

## PLANT AND KERNEL CHARACTERS IN 1928

The individual selections were strikingly uniform in their plant characters, with evidences of segregation in a few selections only. As a lot the group showed marked resistance to lodging and shattering. The threshed samples of grain were uniform in color, with the type of kernel uniform in most samples. The size of kernel in the various samples ranged from small to large, and the texture from soft to vitreous. The majority of the selections were chosen for high protein as indicated by texture and most of them bred true to type.

## DISCUSSION

The object of the multiplication of crosses in bulk for a series of generations is to obtain material suitable for selection. How many generations are necessary before selections are made? This is one of the most important considerations in the use of the bulked-population method. It is important that the type of plant selected remain constant in later generations. In order to select with efficiency, it is necessary that the majority of the hybrid population shall be homozygous. Self-fertilized populations tend to become homozygous automatically, and, in a relatively small number of generations, consist almost entirely of pure lines.

The relative proportions of homozygous and heterozygous plants in any generation, assuming independent segregation, may be calculated by the general formula $h = 1 - \left(\frac{2n-1}{2n}\right)^m$ given by Babcock and Clausen (1), where h equals proportion of homozygotes, n equals number of generations, and m equals the number of pairs of factors involved. Thus, with five pairs of factors, a bulked population of heterozygous individuals would contain about 14.2% after five generations and 7.8% after six generations. With 10 pairs of factors there would be about 26.3% of heterozygotes in the fifth generation and only about 1% in the tenth generation. If linkages are involved the time required would be reduced.

The number of generations required thus depends on the number of factors involved. Ordinarily, crosses involving four or five character differences should be grown through seven or eight generations before selection. Where the cross is wide as many as 8 to 10 generations should be grown. In the more complex crosses the use of the back cross for one or two generations before bulking may be found advantageous in effecting a saving of time.

What area of land should be used for each hybrid generation when sown with a grain drill? The total number of individuals in a population should be large enough so that all combinations desired in the cross will be contained in it. This again is governed by the number of genetic factors involved. With a small number (two to three pairs) of factors, only a small area would be required but as factor differences important in development may occur, and yet be invisible, provision should be made for a reasonably large population.

The number of individuals necessary to secure all possible recombinations in an $F_2$ population (assuming independent segregation) may be calculated for any number of pairs of factors by the general expression $4^n$ (Babcock and Clausen, 2), where n equals the number of pairs of factors. Thus to get all types of recombinations with five pairs of factors 1,024 individuals are necessary; with six pairs, 4,096 individuals; and with 10 pairs, 1,048,576 individuals. In practice, however, combinations usually are made between known varieties with many desirable characters in common, but with relatively few (two or three) significant factor differences.

Rate of seeding is a factor which should be considered in determining area for growing the bulked population. According to McConnell (5), wheat contains, on the average, 10,500 kernels per pound. Approximately, this number was found as the average for Pacific Bluestem (10,080), a variety with midsized kernel, at Chico, Calif., in 1921. Wheat sown at the rate of 80 pounds per acre would contain approximately 80,000 plants on 0.1 acre; 16,000 on 0.02 acre (1/50), and 8,000 plants on 0.01 acre. It would seem that, at the rate of seeding stated, the fiftieth-acre unit should give a reasonable opportunity to secure desired combinations. As succeeding generations are grown, natural selection operates to eliminate low-yielding and unsuitable combinations, thus increasing the chances that the desirable types are included.

## METHOD USEFUL FOR COMPLEX CHARACTERS

The bulked-population method has been used with success in producing winterhardy wheats at Svalof (Newman, 6). This work included the sowing of seed in flats so that exposure to cold could be properly controlled, thus securing the desired elimination of nonhardy individuals. The method also has been used in the development of rust resistance in wheat. Where external infection is highly important, as in stem rust of wheat, an easily identified susceptible variety should be mixed and sown with the cross containing the factors for resistance. In crosses for bunt resistance the smut spores may readily be applied

artificially to the seed sample. In this work thin spacing is important so that individual plants may be readily segregated for examination.

## SUMMARY

The bulked-population method of handling cereal hybrids consists essentially of creating populations by hybridization, growing the hybrids in bulk for six or eight generations until they have become homozygous or nearly so, and then making head or plant selections for comparative testing in the usual way.

Nineteen crosses were handled by this method in an experiment at University Farm, Davis, Calif., in all or part of the years from 1923 to 1926, inclusive. Two generations were grown in each year. Head selections were made in 1926 and were grown in head rows in 1927. The best head rows were sown in replicated 16-foot triple rows in 1928.

The average yields of 33 of the 45 selections grown in 1928, or 73.3% of the total number, were above the average yield of all (33) check rows. As a group the selections showed marked resistance to lodging and shattering. Hard-kerneled types predominated.

The number of generations required before selection depends on the number of character differences involved. Ordinarily, seven or eight generations are sufficient.

The area used for a bulk population should be large enough so that, at the rate of seeding employed, all combinations expected in a cross may be included. On the average, wheat contains 10,500 kernels per pound. From 1 to 2 pounds should be sown when dealing with crosses of ordinary complexity.

The method is adapted for the development of strains possessing such characters as winterhardiness, rust resistance, smut resistance, etc., in the close-fertilized cereals.

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# EFFECT OF DATE OF SEEDING ON YIELD, LODGING, MATURITY, AND NITROGEN CONTENT IN CEREAL VARIETAL EXPERIMENTS[1]

V. H. FLORELL[2]

The range in time of sowing the dry-land cereals in California extends on the average from November to March. Date-of-seeding experiments have shown that the highest yields usually are obtained from grain sown in November or December. This is recognized by the grain grower, but early sowing requires fallow land and the cropping systems employed frequently necessitates winter sowing.

The varietal experiment gives information as to which are the leading varieties in a group, when sown at a more or less definite time. At Davis the varietal experiment is sown in November or December, depending on weather conditions. When sown annually at about the same date, the experiment is conducted under more or less uniform conditions. Seasonal variations, however, produce differences in reaction in varieties. In a season of abundant and well-distributed rainfall a midseason or late variety may give the highest yield of grain, while in a season of less abundant rainfall an early maturing variety may give the best results. Considering such reactions, it is evident that a series of varieties, when sown in February, might and probably would rank differently in yield than when sown in November or December.

It thus would seem unsafe to recommend a certain variety as the best for a California grower to sow in February if the recommendation is based on its reactions in experiments sown in December. The variety giving the best yields when fall sown may be the best for spring sowing, but this should be determined definitely before making recommendations. To obtain exact information on this point, a preliminary varietal date-of-seeding experiment for wheat, barley, and oats was conducted in 1928. The results obtained are presented at this time because of their possible value in suggesting similar experiments to others.

## EXPERIMENTAL METHODS

Relative yields from varieties grown in replicated nursery experiments are fairly consistent with those from the same varieties grown

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in plat experiments. In addition to the saving of expense, the nursery has the advantage that a larger number of varieties can be tested than when plats are used. The practicability of nursery date-of-seeding experiments had been determined previously by the writer (1920 and 1921) at the U. S. Plant Introduction Station, Chico, Calif. Consequently, the experiment was conducted in the nursery, the material being grown at University Farm, Davis, Calif., in cooperation with the California Agricultural Experiment Station. The preliminary experiment here described included 12 cereal varieties. About 0.3 acre of land was required for the entire experiment, whereas if 1/50 acre plats had been used for the same number of varieties, dates, and replications, about 7.6 acres of land would have been needed.

Five varieties each of wheat and barley and two of oats were grown. The list included the most promising varieties of each cereal as determined by previous experiments and also the leading commercial varieties of the section. A few others were added to give a range in time of maturity from early to midseason and late so that data from the different maturity classes might later serve to some extent as a guide for untried varieties.

Each variety, on each date of seeding, was sown in three-row plats replicated four times. The barleys were grown in rows 20 feet long, wheats in rows 16 feet long, and oats in rows 15 feet long, the rows being spaced 1 foot apart with alleys 4 feet wide between series. At the beginning and end of each series of varieties in each replication for each date, a three-row guard plat was grown. The guard rows were necessary as rows located too near those sown on a previous date suffer from unfavorable competition.

Barley and wheat were sown at 12.5 grams per row, and oats at 12 grams. Results show that heavier rates should have been used for barley. The varieties were sown at monthly intervals from December to March, inclusive. It was planned to begin in November, but rainy weather made it necessary to omit this first month. In elaborating this experiment it would be desirable to extend the time range, to sow at shorter intervals, and to increase the number of replications.

## EXPERIMENTAL DATA

### AGRONOMIC AND YIELD DATA

Table 1 records the data on yield, date of maturity, and lodging obtained in 1928 from the different varieties sown on the four dates. The yields of the wheat varieties sown on the four dates are shown in Fig. 1.

TABLE 1.—*Date ripe, percentage of lodging, and yield of wheat, barley, and oat varieties grown in a nursery date-of-seeding experiment at University Farm, Davis, Calif., in the crop year 1927–28.*

| Variety | C. I. No. | Sown December 6 | | | Sown January 12 | | | Sown February 8 | | | Sown March 10 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Date ripe | Lodging % | Yield in bushels | Date ripe | Lodging % | Yield in bushels | Date ripe | Lodging % | Yield in bushels | Date ripe | Lodging % | Yield in bushels |
| | | | | | Wheat | | | | | | | | |
| White Federation | 4981 | June 2 | 0 | 37.8 | June 6 | 0 | 40.2 | June 10 | 0 | 12.5 | June 16 | 0 | 7.3 |
| Baart ........ | 1697 | June 3 | 9 | 27.4 | June 10 | 1 | 22.8 | June 15 | 0 | 12.5 | June 20 | 0 | 6.8 |
| Pacific Bluestem | 4067 | June 7 | 2 | 27.7 | June 11 | 0 | 16.2 | June 18 | 0 | 6.2 | June 25 | 0 | 2.7 |
| Little Club..... | 4066 | June 11 | 1 | 20.9 | June 15 | 0 | 11.7 | June 18 | 0 | 6.7 | June 25 | 0 | 3.0 |
| Pusa No. 4..... | 4791 | May 31 | 9 | 33.2 | June 3 | 0 | 44.5 | June 7 | 0 | 27.4 | June 16 | 0 | 13.3 |
| | | | | | Barley | | | | | | | | |
| Vaughn........ | 1367 | May 21 | 5 | 55.9 | May 26 | 5 | 40.5 | June 3 | 0 | 39.3 | June 10 | 0 | 23.6 |
| Coast.......... | 690 | May 23 | 9 | 40.4 | May 30 | 5 | 45.1 | June 5 | 2 | 42.6 | June 15 | 0 | 21.1 |
| Sacramento.... | 1511 | May 31 | 2 | 57.5 | June 6 | 2 | 43.4 | June 8 | 0 | 33.6 | June 24 | 0 | 13.2 |
| Club Mariout... | 261 | May 20 | 10 | 43.0 | May 27 | 10 | 43.0 | June 4 | 2 | 51.0 | June 15 | 0 | 29.1 |
| Atlas.......... | 4118 | May 20 | 10 | 26.3 | May 28 | 8 | 33.0 | June 4 | 0 | 46.1 | June 16 | 0 | 26.3 |
| | | | | | Oats | | | | | | | | |
| Kanota........ | 839 | May 27 | 8 | 61.6 | June 2 | 7 | 55.9 | June 10 | 3 | 52.0 | June 17 | 0 | 39.1 |
| California Red.. | 1026 | June 1 | 6 | 33.4 | June 7 | 3 | 50.6 | June 15 | 2 | 11.3 | June 24 | 0 | 2.9 |

The regular varietal experiments at Davis over a period of years have shown that White Federation is one of the highest yielding varieties when fall sown. The experiment here reported shows a similar result for the December sowing, White Federation leading Pusa No. 4, the next highest variety, by 4.6 bushels per acre. For the January sowing the result was reversed and Pusa No. 4 led White Federation by 4.2 bushels per acre. In the February and March sowings the relative advantage of Pusa No. 4 was still greater, showing its distinct superiority for late seeding during the season concerned. Both White Federation and Pusa No. 4 are early, short-strawed varieties, but Pusa No. 4 is a few days the earlier. Very low

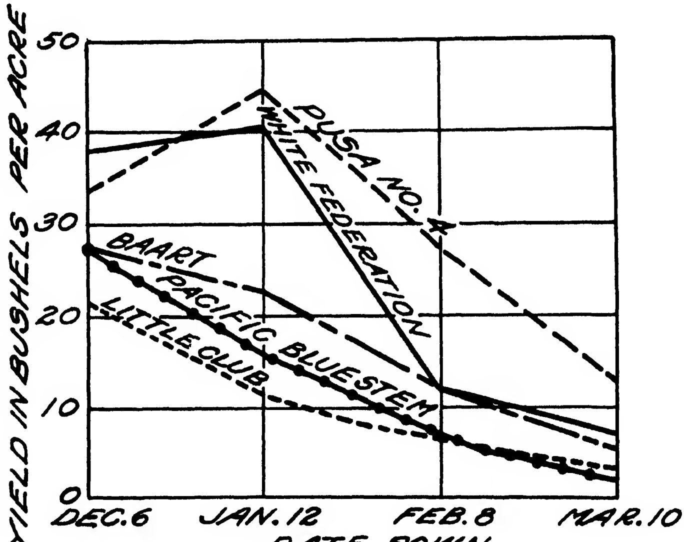


FIG. 1—The yield of five wheat varieties sown on four dates at Davis, Calif., in the crop season of 1927–28.

yields were obtained from both the winter and spring sowings of Pacific Bluestem, a midseason to late variety, and from Little Club, a late variety.

In California many varieties often lodge badly when sown early on fertile soils. Only those varieties with strong and stiff straw remain erect. Such varieties usually are able to produce higher yields of grain than those which lodge. It may be noted that White Federation showed no lodging from the December sowing. Little Club likewise showed very little lodging, but, being late, its yield was reduced by the usual early summer drought.

Table 1 also shows the tendency for the time of maturity to converge when varieties are sown at different dates. In none of the varieties was there more than 18 days difference in the date of maturity of the first and last sowings. The growth period of White Federation from time of sowing, December 6, to date of maturity on June 2 was 178 days, while the growth period for the March 10 sowing was 84 days. Proportionate differences occurred in the intermediate dates of sowing. Notwithstanding the great differences in the growth periods, plump, mature kernels were produced from all dates of seeding. The reduction in yield associated with late seeding came about mainly through reduction in the number of culms per plant and in kernels per spike.

Similar variations in yield and other factors also occurred with the barley and oat varieties. With the exception of the California Red oat, yields, however, were much better from the February and March sowings than in the case of wheat.

The outstanding result from the barley varieties was the relatively high yield of Club Mariout from the late sowings. The variety is weak strawed and often lodges badly early in the season, but this difficulty is much less marked late in the season. Its yielding capacity from late winter sowing no doubt has been an important factor in its wide distribution in California.

Fulghum oat shows a similar high yielding capacity from late sowing. This variety was much superior to California Red, a late-maturing variety commonly grown in California.

The yields obtained from this experiment are suggestive, but it is recognized that additional data must be obtained before positive conclusions can be drawn.

## NITROGEN CONTENT OF GRAIN FROM DIFFERENT DATES OF SEEDING

The total nitrogen content was determined in five varieties each of wheat and barley from each replication in each date of seeding. About 20 grams of a well-mixed sample of each lot of grain (including hulls in barley) was ground finely in a hand grinder. Total nitrogen was determined by the Kjeldahl method on duplicate 1-gram samples. Data on the average percentage of nitrogen calculated to a moisture-free basis are given in Table 2.

The outstanding fact for all varieties of both cereals was the regular increase in nitrogen content from the early to the late sowing. The comparatively high nitrogen content of Little Club wheat from all dates of seeding no doubt was due to abnormal maturity as a result of drought at ripening time. Normally this variety has a com-

paratively low nitrogen content. Pacific Bluestem was similarly affected but to a lesser degree.

The protein content of cereal grains is intimately associated with the nitrogen nutrition of the crop, particularly during the later stages of development. In this case it seems likely that the higher nitrogen content of grain from the later sowings is associated with lower yields, either of grain or straw, or both, or to less complete filling incident to summer drought.

The nitrogen content of barley is an important consideration as the value of barley for brewing purposes is inversely proportional to protein content. Coast barley, considered an excellent brewing barley by European maltsters, had a nitrogen content of 1.46% from the December sowing. This was lower than any other, Club Mariout and Vaughn standing next with 1.69%. From the March sowing Vaughn was lowest with a nitrogen content of 2.12%.

TABLE 2.—*Nitrogen content on a moisture-free basis of wheat and barley varieties grown in a nursery date-of-seeding experiment at University Farm, Davis, Calif., in the crop year 1927–28.**

| Variety | C. I. No. | Nitrogen content | | | |
|---|---|---|---|---|---|
| | | Sown December 6 | Sown January 12 | Sown February 8 | Sown March 10 |
| | | % | % | % | % |
| | | Wheat | | | |
| White Federation... | 4981 | 2.01 | 2.22 | 2.57 | 2.90 |
| Baart............. | 1697 | 2.14 | 2.32 | 2.53 | 2.98 |
| Pacific Bluestem.... | 4067 | 2.06 | 2.66 | 2.78 | 3.01 |
| Little Club........ | 4066 | 2.32 | 3.05 | 3.09 | 3.38 |
| Pusa No. 4........ | 4791 | 2.28 | 2.19 | 2.44 | 2.78 |
| | | Barley | | | |
| Vaughn .......... | 1367 | 1.69 | 1.89 | 2.11 | 2.12 |
| Coast............. | 690 | 1.46 | 1.69 | 2.13 | 2.91 |
| Sacramento........ | 1511 | 1.81 | 1.93 | 2.12 | 3.01 |
| Club Mariout...... | 261 | 1.69 | 1.84 | 1.99 | 2.45 |
| Atlas.............. | 4118 | 1.78 | 1.71 | 1.94 | 2.38 |

*Analyses reported in this table made by F. W. Allen.

## DISCUSSION

The general practice in date-of-seeding experiments with small grains has been to select the leading commercial variety of the cereal in question and to make sowings on appropriate dates during the seeding season. The dates of seeding giving the best yields of the variety used have been considered the best for all commercial varieties of that particular crop grown in that area. Where the seeding season is comparatively limited in range by climatic factors, such procedure may be correct. Where the seeding season extends over a wide

range in date, as in California, the reaction of varieties to each date of seeding seems important. This probably is generally recognized by agronomists, but it has not been given much consideration in planning varietal experiments. A few experiment stations are sowing varietal experiments on several dates, but the practice is not general.

Recognizing the limitations of the above data, the implications are obvious. If the result is in any way indicative of what may be expected over longer periods, it is evident that a varietal experiment sown in November or December does not give all the information necessary for the California farmer. The value of Pusa No. 4 for sowing on the later dates could not be determined by an early-sown experiment. Varieties of merit and usefulness for average farm conditions might be discarded and never reach production on the basis of such information. Nor would the farmer's problem be adequately solved.

The nitrogen relations of the crop from the different dates of seeding also are interesting. Early-sown California wheats ordinarily are starchy and low in protein. With sufficient information at hand, yield might be maintained and bread-making quality improved by seeding a properly chosen variety at some suitable later date. The malting value of late-sown barley similarly might be improved by better information on varietal reaction to late seeding.

The entire problem of varietal reaction to date of seeding seems to merit further investigation.

# VARIATIONS IN POTASSIUM CONTENT OF ALFALFA DUE TO STAGE OF GROWTH AND SOIL TYPE AND THE RELATIONSHIP OF POTASSIUM AND CALCIUM IN PLANTS GROWN UPON DIFFERENT SOIL TYPES[1]

JOHN F. FONDER[2]

Soil type was found to be so important in determining the calcium and magnesium content of alfalfa plants at different stages of growth (5)[3] that a study of its effect upon additional important elements appeared advisable. One of the elements considered was potassium, and data showing the variations in this element which occur in alfalfa plants at different stages of growth when grown upon different soil types are reported in this paper.

This analysis made possible not only a study of variations in the amounts of potassium present in the alfalfa stems and leaves and in their juice, as affected by soil type, but also a comparison of the potassium-calcium ratios in plants obtained from different soil types with a possible explanation of the observed differences.

## HISTORICAL

Physiologists are in agreement upon the essentiality and probably universal occurrence of potassium in plant materials. The existing information indicates that potassium does not enter into the actual composition of the structural material of the plant but occurs rather as precipitation and infiltration products within the tissues and as dissolved products in the plant sap. MacCallum (12) found potassium in both the cytoplasm and extracellular structures of plants, in the latter as a product of impregnation and infiltration and in the former as physiological precipitation and physiological or biochemical condensations.

Dowding (4) determined that potassium was absent from the wood of mature spruce roots during the winter but was plentiful in the meristematic tissue. In roots of other plants the meristematic tissue was found rich in potassium and this element appeared to be

[1]Contribution from the Soils Department, Michigan Agricultural Experiment Station, East Lansing, Mich. Received for publication February 20, 1929.

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[3]Reference by number is to "Literature Cited," p. 750.

associated with the outgrowth of secondary roots. According to Palladin (15), potassium in plants accompanies carbohydrates and is supposed to promote their formation.

In two former papers (5, 6) information bearing upon seasonal variations in the composition of plants and upon the relationship of plant composition to varying soil conditions was given at some length. To these citations may be added the following bearing more specifically upon the element potassium. Palladin (15) reproduces data showing that the percentage of potassium in the ash of beech leaves decreased during the course of the summer, but no corresponding decrease in the absolute amount of potassium was apparent. The absolute amount was maintained fairly constant during the growth period and underwent a marked decrease only in late autumn.

Burd (2) observed that there were three periods of growth in the barley plant. During the first period, ending eight and nine weeks from planting, the increase of potassium conformed very closely to the gain in total weight. At the beginning of the second period a depression occurred in the potassium content, indicating a movement from the plant to the soil. This continued for two weeks, after which there was again an increase in the amount of potassium present until just before maturity, when it dropped slightly.

While it has been largely observed that the addition of various mineral nutrients to the soil as fertilizer generally results in an increased amount of these elements in the plant (8, 13, 14), it has also been noted that the addition of calcium to the soil brings about a decrease of the amounts of potassium present in plants.

Lagatu and Maume (9) showed that the potassium content of grape leaves was lower if the vines were fertilized with a fertilizer containing calcium phosphate than with one carrying superphosphate, and toward the end of the growing period the amount of potassium in the former case would drop below the amount present in the leaves of vines receiving no fertilizer. They concluded that this result was not due to the superphosphate but to the inhibitive action of the calcium, contained in the calcium phosphate, upon the absorption of the potassium.

Crist (3) also raised this question concerning the depressive effect of calcium upon the absorptive powers of root membranes. He found that liming a soil not only depressed the absorption by lettuce roots of certain other elements, but decreased as well the absolute amount of calcium taken up and explained these results as due to the faculty of the calcium ion to make the root membranes less permeable. Unfortunately, potassium was not considered in this work and also only

lettuce plants were grown, which are admittedly acid-tolerant plants and perhaps subject to marked effect by certain amounts of calcium.

Lipman, et al (10) found that in nearly every case the percentage of potash was lower in corn stalks obtained from limed soils than in those obtained from unlimed soils. The lower percentages of potash were considered as undoubtedly due, in part at least, to the exchange of bases, the lime of the applied limestone taking the place of the potash in the soil. Analysis showed the limed soils to be always slightly lower in potash than the unlimed, but the differences were not sufficiently great to account for the differences found in the analysis of the corn stalks. Nor could the greater growth on the limed soils be held responsible for the decrease of potash in the plants from the limed soils. These workers analyzed a limited number of samples of corn stalks for lime and found the content higher on the limed than on the unlimed soils, which was generally the reverse of the results found for the potash. They explained these facts as follows:

"It may be that the repeated applications of lime, having helped to reduce the potash content of the soil, particularly the more readily displaced portion of it, discourages excess consumption of this ingredient. With our present knowledge a positive answer cannot be given. It may also be that on the limed section a part of the plant's basic requirement has been met by the utilization of lime to the exclusion of a part of the potash."

However, as regards the alteration of the supply of potassium available to the plants, due to base exchange induced by additions of lime, Plummer (16) and MacIntire, et al (11) have shown the loss of potassium in lysimeter tests to be actually depressed by the addition of lime, indicating further that base exchange is probably insignificant in such cases.

Recently, McCool and Weldon (14) presented data showing that the addition of calcium, either in the form of lime or in phosphatic fertilizers, reduced the amount of potassium in the juice of several crops. This depression usually varied directly with the size of the application of calcium and at times the effect of the calcium was sufficient to obscure the effect of the addition of potassium in the fertilizers.

Thus it appears that the addition of calcium to soils may be expected to alter the amounts not alone of the calcium present in plants grown upon them, but of other elements as well. Perhaps such variations would also occur under conditions where the natural equilibrium of the soil is not altered by the addition of fertilizers. Evidence bearing upon such a situation will be presented here.

## MATERIALS AND METHODS OF ANALYSIS

The materials used in this work were those obtained for the analysis presented in a former paper (5) dealing with the effect of soil type upon the calcium and magnesium content of the alfalfa plant and fully described in that paper. The samples were obtained from soil types presenting a wide range of textural differences, extending from very light sandy soils on the one hand to very heavy clayey soils on the other. While no effort was made to determine variations in the rate or extent of growth of the plants on the different types, it was noted that with one possible exception all of the soils appeared to offer excellent growing conditions and produced plants of good quality. This one exception was the Brookston clay loam which produced plants somewhat smaller in size and less rapidly growing.

In the analyses 10-cc aliquots of the solutions were used. Potassium was determined by the volumetric method of Adie and Wood (1), and the results are reported as averages of closely agreeing duplicate determinations for each sample.

## EXPERIMENTAL RESULTS

### POTASSIUM CONTENT AT DIFFERENT STAGES OF GROWTH AS INFLUENCED BY SOIL TYPE

#### STEMS

Marked variations in the potassium content of the stems of alfalfa plants grown on the several soil types occurred during the entire period of growth, as well for the second crop as for the first. This is evident in Table 1 where it appears that the stems of plants grown on a particular soil type were consistently either very high or very low in potassium throughout the growth period. The potassium was always high in the plant stems obtained from the very sandy

TABLE 1—*The potassium content of alfalfa stems at different stages of growth on different soil types.**

| Soil Type | Stage of growth: First growth | | | | Second growth | | |
|---|---|---|---|---|---|---|---|
| | May 8 | May 22 | June 7 | July 2 | July 24 | Aug. 2 | Full bloom |
| | % | % | % | % | % | % | % |
| Plainfield... | 7.17 | 4.78 | 2.76 | 2.01 | 4.78 | 5.60 | — |
| Coloma..... | 3.30 | 3.62 | 3.28 | 1.67 | 4.18 | 2.78 | 0.95 |
| Hillsdale..... | 4.14 | 2.94 | 2.36 | 1.17 | 4.03 | 1.96 | — |
| Fox........ | 3.62 | 2.65 | 1.55 | 1.11 | 6.42 | 2.96 | 1.14 |
| Conover.... | 3.22 | — | 0.81 | — | 2.73 | 1.09 | 1.77 |
| Brookston... | 4.50 | 2.80 | 1.50 | 2.03 | 3.05 | 1.80 | 1.97 |
| Miami...... | 2.87 | 1.76 | 1.08 | 1.50 | 3.14 | — | 1.52 |

*Dry basis.

soils, low in those from the lighter loam soils, and either low or only moderately high in those from the heavier loam soils. These variations were so consistent that it apparently precludes any doubt that they were due to soil type differences.

A decided decrease took place in the percentage of potassium present in the stems of the plants from each soil type as the plants became older. This decrease was quite uniform on all of the soil types but not entirely so. The stems of the plants grown on Brookston and Miami soils showed an increase in potassium after the budding stage in the first crop, as did those of the plants from Brookston and Conover soils in the second crop.

About equal amounts of potassium were present in the stems of both the first and second growth alfalfa, it being only slightly higher in those of the first crop. There was no evidence in the second crop that the potassium content of the soil was depleted to the extent that it was limiting the amount of the element available to the plants. Rather, it appears that the potassium content of the plants was a result of definite processes within the plants themselves, perhaps induced by conditions in the soil not evident here.

### LEAVES

While it has been shown (17) that the total ash content of alfalfa leaves is usually higher than that of the stems, the data included in Tables 1 and 2 show that such is not the case with potassium. Recognizing that there were exceptions, the stems of alfalfa generally contained more potassium than the leaves. Due to this smaller quantity of potassium in the leaves, variations of less magnitude occurred at the different stages of growth and also as a result of the influence of soil type. Nevertheless, it is evident from the data in Table 2 that the plant leaves obtained from certain soil types were

TABLE 2.—*The potassium content of alfalfa leaves at different stages of growth on different soil types.**

| Soil type | Stage of growth: First growth | | | | Second growth | | |
|---|---|---|---|---|---|---|---|
| | May 8 | May 22 | June 7 | July 2 | July 24 | Aug. 2 | Full bloom |
| | % | % | % | % | % | % | % |
| Plainfield... | 4.63 | 1.69 | 3.02 | 2.26 | 2.38 | 3.68 | — |
| Coloma..... | 2.98 | 1.82 | 2.02 | 2.13 | — | 2.50 | 1.14 |
| Hillsdale.... | 2.70 | 2.18 | 1.56 | 1.34 | 2.93 | 1.75 | — |
| Fox........ | 2.22 | 1.90 | 1.22 | 0.95 | 2.67 | 2.22 | — |
| Conover.... | 2.40 | 1.64 | 0.67 | — | 1.83 | 1.40 | 0.74 |
| Brookston... | 3.02 | 2.05 | 1.14 | 1.39 | 1.92 | 1.62 | 1.60 |
| Miami...... | 1.62 | 1.50 | 0.88 | 2.20 | 1.91 | — | 1.62 |

*Dry basis.

characteristically higher in potassium than were those obtained from other soil types. Here again, as was found for the stems, the leaves of the plants grown on the very sandy soils were generally higher in potassium than those of the plants grown on the heavier soils. However, the leaves obtained from the lighter loams, such as Fox and Conover, were not always lowest in potassium, sometimes containing slightly more potassium than the leaves obtained from the heavier soil types.

A decrease took place in the percentage of potassium present in the alfalfa leaves as the growth period advanced. This occurred at about the same rate in both the first and second crops, and it is again evident that the decrease was probably not induced by a deficiency of potassium in the nutrient medium but rather by the nature of the plants themselves. The decrease of potassium in the leaves was less uniform than in the stems and it also was slower, even to the extent that on the Miami soil there was a greater amount of potassium present at the full bloom stage of the first crop than was present at the beginning of growth.

### JUICE OF STEMS

The influence of soil type on the concentration of potassium in the expressed juice of alfalfa stems is plainly evident in Table 3. In the first crop the juice of the stems grown on the very sandy soils was richer in potassium during the entire growth period, while that obtained from stems grown on the light loams was lowest in potassium. Apparently the juice of the stems obtained from the heavy loams was higher in relation to that of the juice obtained from the stems grown on the other soil types than was found in the case of the tissue of the stems. As a result of this, soil texture is not so evidently a factor in determining the potassium content of the expressed juice of the stems.

TABLE 3—*The potassium content of the expressed juice of alfalfa stems at different stages of growth on different soil types.*

| Soil type | Stages of growth | | | | | |
|---|---|---|---|---|---|---|
| | First growth | | | | Second growth | |
| | May 8 | May 22 | June 7 | July 2 | Aug. 2 | Full-bloom |
| | % | % | % | % | % | % |
| Plainfield | 1.16 | 0.64 | 0.53 | 0.64 | 0.83 | — |
| Coloma | 0.65 | 0.46 | 0.40 | 0.42 | 0.41 | 0.32 |
| Hillsdale | 0.72 | 0.35 | 0.37 | 0.41 | 0.44 | — |
| Fox | 0.48 | 0.39 | 0.36 | 0.31 | 0.74 | 0.67 |
| Conover | 0.44 | 0.27 | 0.13 | — | 0.28 | — |
| Brookston | 1.08 | 0.53 | 0.41 | 0.51 | 0.42 | 0.43 |
| Miami | 0.55 | 0.31 | 0.23 | 0.50 | — | 0.40 |

A decided decrease took place in the concentration of potassium in the expressed juice of the stems of both the first and second crops. In the first crop the greatest decrease appeared between the first and second samplings, after which only a slight reduction in concentration occurred and in some instances an increase took place.

Slightly less potassium was present in the expressed juice of second growth stems at full bloom than was present in that of the first growth stems. But since at the budding stage the concentration was greater in the juice of the second crop stems it required that a greater decrease take place in the amount of potassium present in the juice of the stems of the second crop after the budding stage. This may be an indication of the depletion of the potassium content of the nutrient medium.

### JUICE OF LEAVES

In Table 4 are presented the percentages of potassium found in the expressed juice of alfalfa leaves obtained from the different soil types. Not only were there great variations in the amounts of potassium present in the expressed juice of leaves obtained from the different soil types, but the variances appeared to follow a very orderly arrangement. The influence of soil type is brought out plainly by the fact that the juice of the leaves of plants grown on a particular soil type was consistently high or low in potassium during the entire growth period. Also, the effect of soil texture is quite evident, as there was a decrease in the concentration of potassium in the juice of the leaves as the soils from which the plants were obtained became heavier. Here, as with the stems, this does not always hold, as the very heavy soils gave plant leaves the juice of which contained more potassium than was found in the juice of the leaves from the loam soils.

TABLE 4.—*The potassium content of the expressed juice of alfalfa leaves at different stages of growth on different soil types.*

| Soil type | Stage of growth: First growth | | | | Second growth | |
|---|---|---|---|---|---|---|
| | May 8 | May 22 | June 7 | July 2 | Aug. 2 | Full bloom |
| | % | % | % | % | % | % |
| Plainfield | 0.80 | 0.55 | 0.41 | 0.56 | 0.60 | — |
| Coloma | 0.78 | 0.47 | 0.30 | 0.37 | 0.43 | 0.36 |
| Hillsdale | 0.78 | 0.35 | 0.49 | 0.43 | 0.40 | — |
| Fox | 0.55 | 0.37 | 0.30 | 0.29 | 0.55 | 0.57 |
| Conover | 0.52 | 0.31 | 0.19 | — | 0.29 | — |
| Brookston | 0.53 | 0.46 | 0.29 | 0.41 | 0.45 | 0.52 |
| Miami | 0.44 | 0.35 | 0.23 | 0.44 | — | 0.36 |

At the full bloom stage the concentration of potassium in the juice of the leaves was much less than it was at the beginning of growth. The decrease in concentration was not uniform except on two soil types, and it was much more rapid between the first two samplings than later in the growth period. This is in accord with the results found in the expressed juice of the stems.

Generally, there was a greater concentration of potassium in the juice of second growth leaves than there was in that of first growth leaves, which was the reverse of the condition existing in the juice of the stems. Thus, it appears probable that the decrease of potassium noted in the juice of the stems was not due to a depletion of potassium in the nutrient medium, but was instead the result of a physiological change within the plants.

The concentration of potassium in the juice of the alfalfa leaves agreed very closely with that of the juice of the stems. While a number of instances occurred where this was not true, it is still evident that generally the concentration of potassium in the two plant parts was nearly the same.

In a former paper (5) the specific gravity of the expressed juice of the stems and leaves of alfalfa was shown to increase greatly with advancing age in the plants, being more evident in the leaves than in the stems. Since it develops here that the potassium content of the juice of the stems and leaves decreased noticeably during the period of growth, it follows that potassium is not an important cation in determining the specific gravity of the juice. This statement is further borne out by the fact that the specific gravity of the juice of the leaves was formerly shown to be markedly greater than that of the stems, while here it appears that the potassium content of the stems was generally greater than that of the leaves.

Evidently soil type was responsible for marked variations in the percentages of potassium present in the alfalfa plants throughout the growing period and soil texture was one of the soil characters responsible, in part at least, for these variances.

### WOODY TISSUE OF GREEN STEMS AND LEAVES

It has been shown (5) that the proportions of calcium present in the juice and in the woody tissue of plants varied in the stems and leaves and also in plants of different ages. Slightly less than 50% of the calcium of the stems is held in the woody tissue in early growth, but it increases in this tissue until it is slightly more than half in the older plants. In the leaves usually a little less than half of the calcium of the green material is present in some form in the woody

tissue throughout the growing period. A much smaller part of the magnesium of both stems and leaves is present in the woody tissue of the green material in the young plants, but it increases until it is largely contained in the woody tissue when the plants are in full bloom.

The data given in Tables 5 and 6 obtained by the method previously described (5), shows that a very small part of the potassium found in the green material of the alfalfa stems and leaves was present in the woody tissue. In other words, the potassium present in the green material of the alfalfa plant is largely in solution in the sap. While this is the generally accepted view, this work affords further substantial evidence.

TABLE 5.—*Relative amounts of potassium in the woody tissue of young and old alfalfa stems.*

| | Early stage | | Maturity | | |
|---|---|---|---|---|---|
| Soil type | Mgm K in 1 gram green material | Mgm K in 1 gram woody tissues of green material | Mgm K in 1 gram green material | Mgm K in 1 gram woody tissue | Amount added to tissue, mgms |
| Plainfield..... | 10.33 | 0.43 | 5.23 | 0.53 | 0.10 |
| Coloma....... | 5.96 | 0.56 | 4.37 | 1.25 | 0.69 |
| Hillsdale...... | 6.68 | 0.65 | 3.05 | 0.04 | —0.61 |
| Fox.......... | 5.86 | 1.98 | 2.45 | 0.05 | —1.93 |
| Conover...... | 5.22 | 1.54 | — | — | — |
| Brookston.... | 8.73 | 0.04 | 4.23 | 0.28 | 0.24 |
| Miami........ | 4.97 | 0.42 | 4.08 | 0.36 | —0.06 |

TABLE 6.—*Relative amounts of potassium in the woody tissue of young and old alfalfa leaves.*

| | Early stage | | Full bloom | | |
|---|---|---|---|---|---|
| Soil type | Mgm K in 1 gram green material | Mgm K in 1 gram woody tissue of green material | Mgm K in 1 gram green material | Mgm K in 1 gram woody green material | Amount K added to tissue, mgms |
| Plainfield..... | 8.67 | 2.14 | 5.22 | 0.91 | —1.23 |
| Coloma....... | 6.85 | 0.85 | 5.08 | 2.26 | +1.41 |
| Hillsdale...... | 5.72 | — | 3.02 | — | — |
| Fox.......... | 4.97 | 0.70 | 2.34 | 0.14 | —0.51 |
| Conover...... | 5.08 | 0.96 | — | — | — |
| Brookston..... | 6.88 | 2.74 | 3.66 | — | — |
| Miami........ | 3.77 | 0.31 | 6.00 | 1.83 | +1.52 |

These data indicate about equal amounts of potassium in the green material of the stems and the leaves throughout the growth period.

It is also evident that the amount of potassium deposited in the woody tissue is about equal in the two plant parts, at least in the early stages of growth. A slightly greater deposition appears to have taken place in the woody tissue of the leaves obtained from certain of the soil types; and even in the plants which showed a loss of potassium in the woody tissue with advancing age, the decrease was of such a nature that the potassium content of the woody tissue of the leaves was greater.

Soil type appeared to influence the amount of potassium held in the woody tissue of the stems and leaves but no very definite effect can be attributed to soil texture. It does appear, however, that in the plants obtained from the sandy soils, if the woody tissue of some of the stems was high in potassium in early growth, in comparison with that of some other stems, such a decrease occurred that the relative positions of the plant stems was reversed at full bloom. It also appears that if the potassium present in the woody tissue of the stems was high that present in the woody tissue of the leaves was generally low, due perhaps to a functional balance between the two plant parts.

## POTASSIUM-CALCIUM RELATIONSHIP IN ALFALFA ON DIFFERENT SOIL TYPES

Early in the analysis of the plant materials used in this work it appeared that there was a possible relationship between the amounts of potassium in the plants and their calcium contents. With such a possibility in mind, the data presented in the preceding tables and those given in the paper (5) previously mentioned dealing with the calcium content of the alfalfa plant were used as a basis for the figures appearing in the following pages. The interesting facts brought out in these figures make the repetition of the data well worth while.

As was brought out earlier in this paper, the alfalfa plants grown on the very sandy soils were high in potassium, those grown on the medium textured soils were low in potassium, while those grown on the very heavy soils were medium in their content of this element. A condition generally the reverse of this existed in the case of the element calcium and the extent to which a high calcium content was accompanied by a low potassium content is brought out in Figs. 1 to 4, inclusive. It must be recognized that the potassium and calcium contents were usually of a different order of magnitude and are represented in these figures by different scale values.

In Parts A, B, C, and D of Fig. 1 are shown the potassium and calcium contents at four successive stages during the period of

growth of alfalfa stems obtained from seven soil types. The soil types are arranged from left to right in order of increasing fineness of texture. It is immediately apparent that on each soil type the

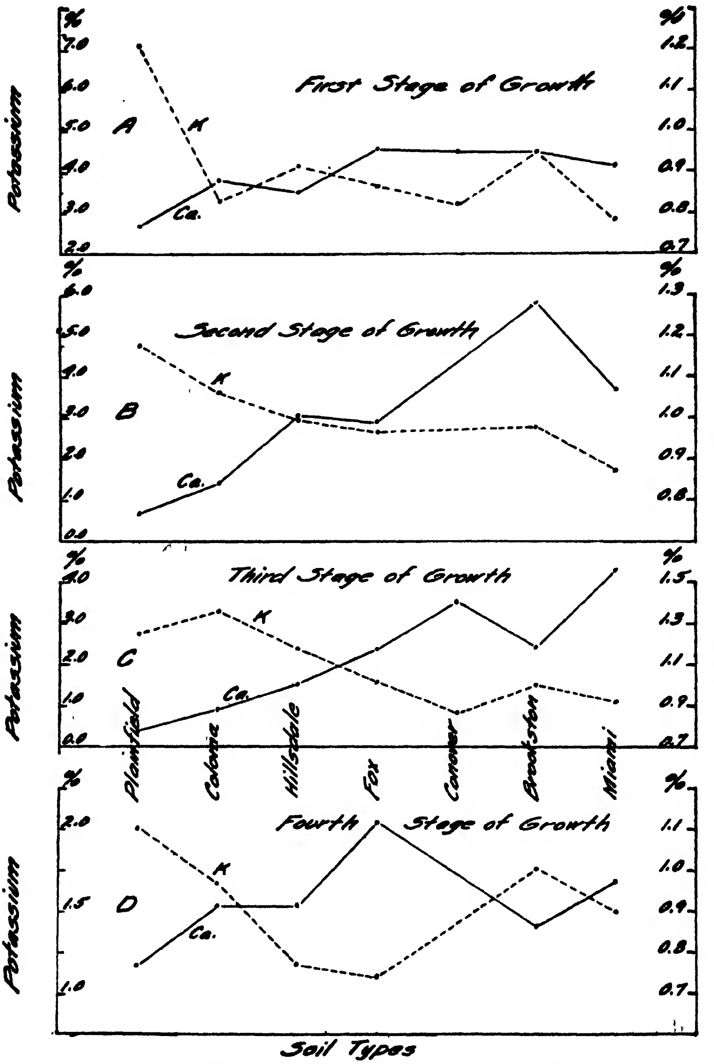


FIG. 1.—The potassium-calcium relationship in alfalfa stems grown on different soil types.

potassium content of the stems of the very young plants, sampled on May 8, was much greater than the calcium content. As the growth period advanced the percentages of the two elements became more

nearly equal until at the stage of full bloom they were of nearly the same magnitude, with the amount of potassium usually slightly greater. The general tendency in the stems of all of the plants for the potassium content to decrease and for the calcium content to increase with advancing age was responsible for this.

Not only is the general slope of the curves representing the potassium contents of the stems of the plants obtained from the different soil types, arranged as stated above, a negative slope and that of the curves representing the corresponding calcium contents a positive slope, but, also, fluctuations in the slope of the curves for one of the elements is more generally than not accompanied by opposite fluctuations in the slope of the curves for the other element. These facts indicate that if the potassium content of the stems was high in plants obtained from a certain soil type, the calcium content was low. Variations in the potassium content of the stems of plants obtained from the different soil types were accompanied by opposite variations in the calcium contents. The coefficient of correlation between the amount of calcium and potassium found in the stems of plants obtained from the different soil types was found to be $-0.8480 \pm .0372$.

A much different potassium-calcium ratio existed in the leaves of the alfalfa plants studied than was found in the stems as appears in Parts A, B, C, and D of Fig. 2. Here, even in the early stage of growth, the calcium content was nearly equal to the potassium content and by the second sampling, taken on May 22, the amounts of the two elements present in the leaves were practically equal. As the plants grew older, accompanied by the increase in calcium and the decrease in potassium formerly noted, the percentage of calcium became noticeably greater than the percentage of potassium, being shown in Part C of Fig. 2, on the same scale as the potassium, and in Part D on a larger scale.

As was noted in the stems, an inverse correlation also existed between the calcium and potassium contents of the leaves obtained from the different soil types. While the general tendency was not so marked for the potassium content to be high and the calcium content to be low in the leaves of the plants grown on the sandy soils, and the opposite for the plants grown on the heavy soils, if the potassium content were high in the plant leaves obtained from a certain soil type, the calcium content was usually low. The most evident departures from this appeared in the samples obtained on May 22, where the correlation between the two elements was very nearly direct, the plants containing a high percentage of potassium

also containing a high percentage of calcium. Also, throughout the growth period the plants grown on the very heavy soils failed to conform to the inverse correlation to any great extent. Notwith-

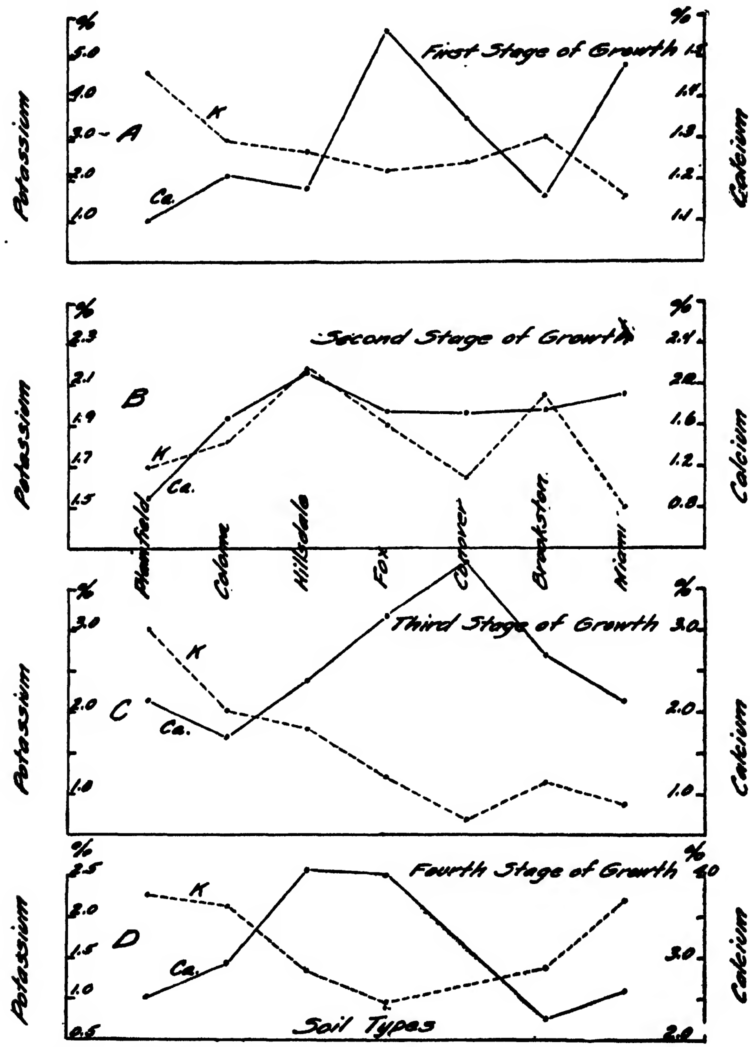


FIG. 2.—The potassium-calcium relationship in alfalfa leaves grown on different soil types.

standing these discrepancies, there was evidently a distinct negative correlation between the amounts of calcium and potassium present in the leaves of plants obtained from the different soil types. A

coefficient of correlation, worked out from the data represented in Fig. 2, was found to be —0.6295 ± 0.785. Thus, if the potassium content of alfalfa leaves obtained from a certain soil type is high,

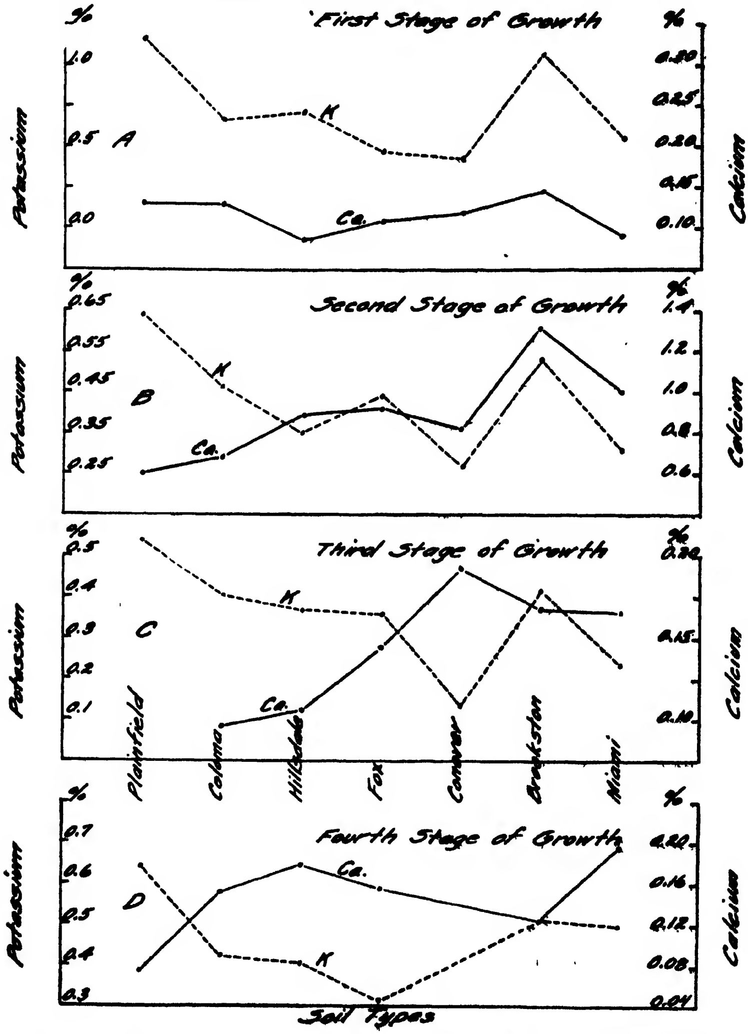


FIG. 3.—The potassium-calcium relationship in the juice of alfalfa stems grown on different soil types.

speaking relatively, the calcium content may be expected to be low, also relatively.

The relationship of potassium and calcium in the expressed juice of alfalfa stems and leaves is brought out in Figs. 3 and 4, respectively.

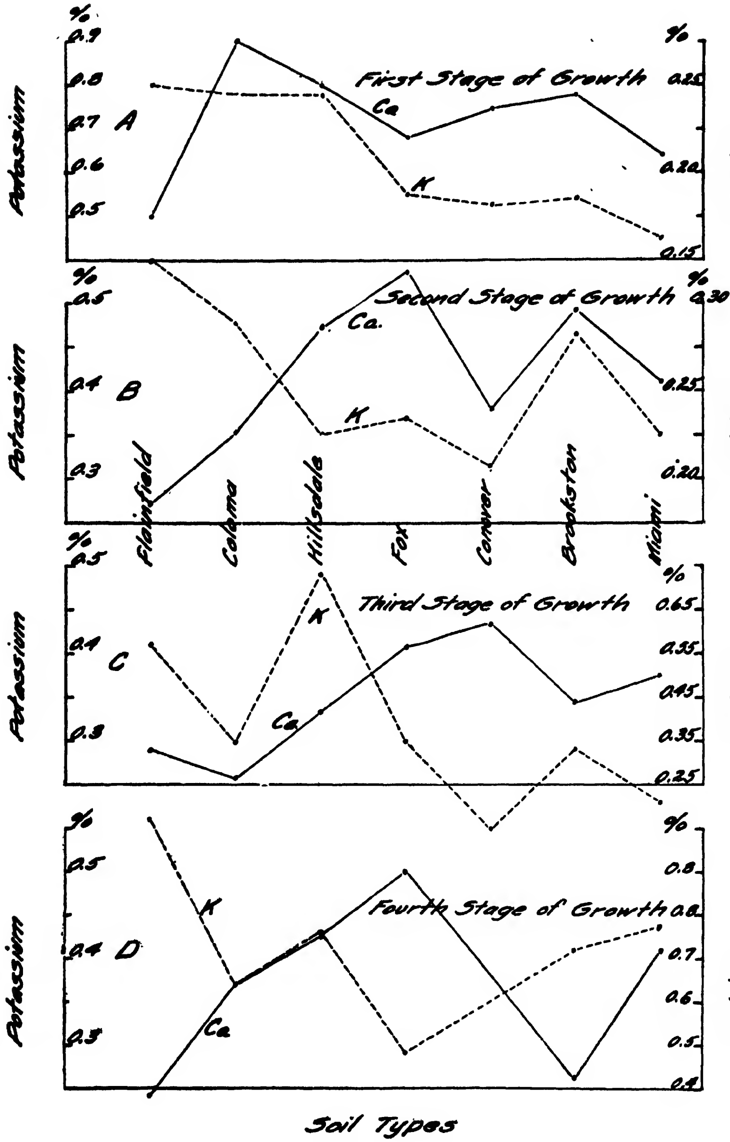


FIG. 4.—The potassium-calcium relationship in the juice of alfalfa leaves grown on different soil types.

Here, as was noted in the tissue of stems and leaves, the proportion of potassium was much greater in the juice of the stems than in that of the leaves. In the latter case, the amounts of calcium became

about equal to the amounts of potassium by the time the plants had reached the budding stage and were considerably greater when the plants were in full bloom. In Fig. 3 the calcium content of the juice of the stems is always shown on a smaller scale than the potassium content, for at no time did the amount of the former approach in magnitude the amount of the latter.

An inverse correlation between the amounts of potassium and calcium present in the expressed juice of the stems and leaves obtained from the different soil types is clearly indicated in these figures. Some disagreements are evident in both Figs. 3 and 4, these usually occurring in the juice expressed from the plants grown on the very heavy soils. Thus, in the early growth, the plants on Miami and Brookston soils, and to a less degree the plants obtained from Conover soil, showed a direct correlation between the amounts of potassium and calcium present in their expressed juice rather than an inverse correlation. Unlike the small discrepancies which might be expected, these are so well established that they must be the result of physiological arrangements within the plants induced by characteristics of these particular soil types. Fig. 4 shows that during the entire growth period the concentrations of potassium and calcium in the expressed juice of the leaves obtained from the different soil types showed a smaller negative correlation than was noted in any previous instance. A coefficient of correlation obtained for the amounts of potassium and calcium present in the expressed juice of the stems grown on the different soil types was found to be $-0.9424 \pm .0148$, while for the leaves grown on the various soil types it was found to be $-0.4909 \pm .0984$.

It appears, then, that variations in the potassium content of the juice of the stems and leaves induced by soil type differences may be expected generally to be accompanied by opposite variations in the calcium content, although this is less true in the case of the juice of the leaves than in that of the stems.

As was stated previously, the results obtained by a number of workers on the addition of fertilizers to the soil have indicated some form of interdependence between calcium and potassium, either in the soil or in the plants. The data just reported also indicate this relationship between potassium and calcium, but they do not involve any addition of fertilizer to the soil with the resultant alteration of the soil equilibrium.

It was formerly shown (6, 7) that growing plants greatly reduce the supply of available calcium in the soil and that the amount of this element present in the plant may depend upon the amount of it

available for absorption. Also, data have been given (5) which appear to indicate the dependence of the calcium in the alfalfa plant upon the supply in the soil to the extent that this element was obtained by the plants of the second crop with increasing difficulty as the growing season advanced. This dependence could be stated definitely only after a study of the solutions of the soils used here. In the present work, on the other hand, there is no evidence that any of the plants were limited in the amount of potassium available to them. In fact, the plants obtained from the admittedly weak soils usually contained a much larger amount of potassium than did those obtained from the stronger soils.

Since it is established here that a high potassium content in the alfalfa plant is usually accompanied by a low calcium content, and inversely a low potassium content by a high calcium content, it appears that the alfalfa plants established a physiological balance between potassium and calcium. While this would indicate that these elements are interchangeable within the plants and would seem to bear out the possibility expressed by Lipman and his coworkers (10) that a part of the plant's basic requirements is met by the calcium, it does not necessarily ascribe a common function to these two elements. It is not impossible that there may be a balancing of functions depending upon the amounts of the elements present.

It seems probable that calcium determines the K/Ca ratio, and also, that the plant will utilize calcium at the expense of the potassium provided it is available. Thus, wherever a larger amount of calcium was available to the plants, as indicated by the composition of the plant material, a smaller amount of potassium was utilized, even though larger amounts of it were probably available than in instances where it was utilized to a greater extent.

While this inverse relationship between potassium and calcium is regarded here as the result of a physiological balance within the plants, the rôle of soil type is not lost sight of. In fact the cause of this balance within the plants appears to be the amount of calcium available for absorption by the plants and this must vary among the different soils. To this extent the situation is a function of soil type.

## SUMARY AND CONCLUSIONS

The stems and leaves and the juice of stems and leaves of alfalfa plants grown upon different soil types were analyzed for potassium at a number of stages during the growth period. Variations in the potassium content of the alfalfa plant at different hours of the day were noted as was also the relationship of potassium to the specific

gravity of the expressed juice of the plant parts. The relative distribution of potassium in the sap and in the woody tissue of the plants was determined. A consideration of the physiological relationship between the elements potassium and calcium was made.

Soil type differences were responsible for marked variations in the potassium content of alfalfa stems and leaves and of their juice. The greatest percentages of potassium were present in the plants grown upon the light sandy soils, medium amounts were present in the plants obtained from the very heavy soils, and the smallest amounts in the plants from the sandy loam soils. The potassium content of the plants was not an exact function of soil texture.

Greater amounts of potassium were present in alfalfa stems than in the leaves, while about equal amounts were present in the expressed juice of the two plant parts. There was a decided decrease in the percentage of potassium present in the stems and leaves and in their juice as the growth period advanced.

About equal amounts of potassium were present in the plants of the first and second crops and apparently the potassium content of the soil was not depleted at any time to the extent that it controlled the percentage of potassium contained in the plants.

Potassium evidently was not an important cation in determining the specific gravity of the expressed juice of alfalfa stems and leaves, an increase in the specific gravity usually occurring in spite of a decrease in the concentration of potassium in the juice.

The potassium present in the green material of the alfalfa stems and leaves existed largely in solution in the plant sap, very little of it being held intimately in the woody tissue. About equal amounts of potassium were present in the woody tissue of the stems and leaves, although slightly more was deposited in the woody tissue of the leaves by the full bloom stage. In the plants obtained from some soil types increasing amounts of potassium were deposited in the woody tissue, while in the plants from the other soil types a decrease occurred during the growth period.

A physiological balance appeared to exist in the alfalfa plants between the elements potassium and calcium. An inverse correlation was established between these two elements in the plants obtained from the different soil types, an increased calcium content being found to be accompanied by a decreased potassium content, both at different stages of growth and in the different plant parts.

Potassium and calcium appeared to be interchangeable in the plants, although not necessarily alike functionally. The potassium content of the plants depended upon the calcium content, which

in its turn appeared to be dependent upon the available supply of this element in the soil, although this last cannot be stated definitely until further data are obtained.

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# LUXURY CONSUMPTION OF POTASSIUM BY PLANTS AND ITS SIGNIFICANCE[1]

R. P. BARTHOLOMEW AND GEORGE JANSSEN[2]

It has been frequently noted that there seems to be quite marked differences in the requirements of plants for various elements. In fact requirements have appeared to be so divergent for some elements that crops have been divided into groups having high and low requirements, *viz.*, calcifuges, low lime, and calcifuces high lime. Groupings have also been made with regard to the nitrogen, phosphorus, and potassium requirements of plants.

It has been noted by several investigators (2, 3, 6, 7)[3], that plants will take up more potassium than is apparently required for normal growth. Just how prevalent this ability is in crops is not known.

The investigation reported in this paper was started in order (a) to secure additional information on the so-called luxury feeding of plants on potassium and (b) to determine the significance of the luxury feeding in plant nutrition.

The work reported in this paper was done in conjunction with some other studies which were made to determine the relationship of potassium to various functions of the plant. The experiments were conducted in the greenhouse and in the field. In the greenhouse, soil, sand, and solution cultures were used for the various crops. In all cases, unless otherwise noted, an abundant supply of all the plant food constituents excepting potassium was added to the cultures. Thus potassium was the only constituent which should have determined the amount of growth which was made. An optimum moisture content of the soil and sand cultures was maintained as nearly as possible. In the field plats the fertilizers were broadcast uniformly by hand shortly before planting and worked into the soil by the seeding operations. The soil has been classified as a Clarksville silt loam by the U. S. Soil Survey and is supposed to be rather well supplied with total potassium.

The crops grown were alfalfa, Hubam clover, cowpeas, soybeans, oats, wheat, Sudan grass, corn, and cotton. The crops were sampled at different stages of growth. When only one sample was taken, it was secured when the crop was beginning to blossom. When several samples were taken, the first one was secured in the early stages of growth and the second when the plant was in blossom.

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[2]Assistant Agronomists.

[3]Reference by number is to "Literature Cited," p. 765.

TABLE 1.—*Potassium content of plants grown in quartz sand with potassium concentrations indicated.*

| K added in p.p.m. | K in plants sampled 48 days after planting % | K in plants sampled 75 days after planting % | K in plants sampled 107 days after planting % | K in plants sampled 136 days after planting % |
|---|---|---|---|---|
| 0 | —* | —* | —* | —* |
| 1 | 0.64 | 0.43 | 0.49 | 0.56 |
| 2 | 0.83 | 0.60 | 0.39 | 0.40 |
| 5 | 1.38 | 0.71 | 0.63 | 0.53 |
| 10 | 1.73 | 1.29 | 0.85 | 0.68 |

*Not enough material for analysis.

TABLE 2.—*Potassium content of some nonleguminous plants grown with increments of potassium in the cultures indicated.*

| Kind of culture | Age of plants in days A | Age of plants in days B | K added* | K in plants, % A | K in plants, % B |
|---|---|---|---|---|---|
| | | | Corn Stems | | |
| Field | 66 | | Check | 2.92 | |
| | | | 0 | 2.12 | |
| | | | 150 lbs. per acre | 3.70 | |
| | | | 300 lbs. per acre | 4.44 | |
| | | | 450 lbs. per acre | 5.03 | |
| | | | Corn Leaves | | |
| Field | 66 | | Check | 2.22 | |
| | | | 0 | 1.78 | |
| | | | 150 lbs. per acre | 2.51 | |
| | | | 300 lbs. per acre | 2.84 | |
| | | | 450 lbs. per acre | 2.36 | |
| | | | Cotton (Whole Plant) | | |
| Field | 70 | | Check | 1.95 | |
| | | | 0 | 1.91 | |
| | | | 150 lbs. per acre | 2.28 | |
| | | | 300 lbs. per acre | 2.70 | |
| | | | 450 lbs. per acre | 2.63 | |
| | | | Cotton | | |
| Solution | 81 | | 0.0 p.p.m. | 0.78 | |
| | | | 0.5 p.p.m. | 0.81 | |
| | | | 1.0 p.p.m. | 1.18 | |
| | | | 2.0 p.p.m. | 1.10 | |
| | | | 3.0 p.p.m. | 1.48 | |
| | | | 5.0 p.p.m. | 1.80 | |
| | | | Oats | | |
| Field (1927) | 86 | 86 | Check | 2.69 | 2.57 |
| | | | 0 | 2.79 | 2.89 |
| | | | 150 lbs. per acre | 3.43 | 2.93 |
| | | | 300 lbs. per acre | 2.16 | 3.11 |
| | | | 450 lbs. per acre | 2.98 | 2.96 |

*Pounds per acre are for muriate of potash.

TABLE 2—*Concluded.*

| Kind of culture | Age of plants in days A | B | K added* | K in plants, % A | B |
|---|---|---|---|---|---|
| | | | Oats | | |
| Field (1928) | 80 | | Check | 0.92 | |
| | | | 0 | 1.12 | |
| | | | 150 lbs. per acre | 1.25 | |
| | | | 300 lbs. per acre | 1.61 | |
| | | | 450 lbs. per acre | 1.63 | |
| | | | Oats | | |
| Solution | 50 | | 0.5 p.p.m. | 1.22 | |
| | | | 1.0 p.p.m. | 1.34 | |
| | | | 2.0 p.p.m. | 2.40 | |
| | | | 3.0 p.p.m. | 2.61 | |
| | | | 5.0 p.p.m. | 3.03 | |
| | | | 10.0 p.p.m. | 1.96 | |
| | | | 25.0 p.p.m. | 3.52 | |
| | | | 50.0 p.p.m. | 3.33 | |
| | | | Sudan Grass | | |
| Field | 56 | 89 | Check | 1.60 | 1.30 |
| | | | 0 | 1.36 | 1.36 |
| | | | 150 lbs. per acre | 1.95 | 1.36 |
| | | | 300 lbs. per acre | 2.02 | 1.19 |
| | | | 450 lbs. per acre | 1.98 | 1.14 |
| | | | Sudan Grass | | |
| Solution | 38 | | 0 p.p.m. | 0.22 | |
| | | | 0.5 p.p.m. | 0.52 | |
| | | | 1.0 p.p.m. | 0.68 | |
| | | | 2.0 p.p.m. | 0.92 | |
| | | | 3.0 p.p.m. | 0.84 | |
| | | | 5.0 p.p.m. | 1.07 | |
| | | | Wheat | | |
| Soil | 61 | 118 | Check | 4.50 | 3.40 |
| | | | 0 | 4.05 | 2.45 |
| | | | 100 lbs. per acre | 5.20 | 2.75 |
| | | | 300 lbs. per acre | 5.55 | 3.36 |

*Pounds per acre are for muriate of potash.

In all cases the samples were made as large as possible in order to eliminate errors due to plant variations. The number of plants taken from the field plats varied from 30 to 100 plants per treatment, while the samples taken in the greenhouse were secured from several jars receiving the same treatment. The samples were first air dried and then dried in the oven at 100°C. They were ground and the potassium content of the plant tissue determined. A few of the analyses have been reported with other experiments (3, 6) but for completeness are included here.

The results of an experiment with oats are given in Table 1. The results are more or less self explanatory. It will be noted that the per-

centage of potassium in the plant increases with the increment in the application. The differences are very marked for the early stages of growth, but they become less marked as the plants become older due to more rapid growth taking place from the larger applications of potassium. The differences in the percentage of potassium in the oats from the field plats in 1927 and 1928 are interesting. The crop in 1927 was followed by a crop of soybeans which yielded 2.3 tons of hay per acre. It is possible that the supply of available potassium was greatly reduced by that crop, thus causing a decrease in the potassium available for the oats in 1928. The full significance of these data will be discussed in detail later.

TABLE 3.—*Potassium content of some legumes grown with increments of potassium in the cultures indicated.*

| Kind of culture | Age of plants in days A | Age of plants in days B | K added* | K in plants, % A | K in plants, % B |
|---|---|---|---|---|---|
| | | | Alfalfa | | |
| Solution | 59 | | 0.5 p.p.m. | 1.76 | |
| | | | 1.0 p.p.m. | 1.54 | |
| | | | 2.0 p.p.m. | 2.17 | |
| | | | 3.0 p.p.m. | 1.90 | |
| | | | 5.0 p.p.m. | 2.24 | |
| | | | Cowpeas | | |
| Field | 36 | 51 | Check | 2.25 | 2.13 |
| | | | 0 | 2.29 | 2.26 |
| | | | 150 lbs. per acre | 2.95 | 2.33 |
| | | | 300 lbs. per acre | 3.00 | 2.32 |
| | | | 450 lbs. per acre | 3.38 | 3.02 |
| | | | Cowpeas | | |
| Solution | 38 | | 0.5 p.p.m. | 0.71 | |
| | | | 1.0 p.p.m. | 0.81 | |
| | | | 2.0 p.p.m. | 1.08 | |
| | | | 3.0 p.p.m. | 1.20 | |
| | | | 5.0 p.p.m. | 1.34 | |
| | | | Hubam Clover | | |
| Field | —† | —† | Check | 2.12 | 1.75 |
| | | | 0 | 2.12 | 1.02 |
| | | | 150 lbs. per acre | 1.92 | 1.57 |
| | | | 300 lbs. per acre | 1.61 | 1.57 |
| | | | 450 lbs. per acre | 1.70 | 1.70 |
| | | | Hubam Clover | | |
| Solution | 56 | | 0.0 p.p.m. | 1.01 | |
| | | | 0.5 p.p.m. | 1.71 | |
| | | | 1.0 p.p.m. | 2.67 | |
| | | | 2.0 p.p.m. | 2.58 | |
| | | | 3.0 p.p.m. | 2.71 | |
| | | | 5.0 p.p.m. | 2.60 | |

*Pounds per acre are for muriate of potash.
†1927 and 1928, respectively.

TABLE 3—*Concluded.*

| Kind of culture | Age of plants in days A | B | K added* | K in plants, % A | B |
|---|---|---|---|---|---|
| | | | Soybeans | | |
| Field | 37 | 52 | Check | 1.38 | 1.56 |
| | | | 0 | 1.65 | 1.27 |
| | | | 150 lbs. per acre | 1.94 | 1.68 |
| | | | 300 lbs. per acre | 2.34 | 1.54 |
| | | | 450 lbs. per acre | 2.07 | 1.87 |
| | | | Soybeans | | |
| Field | 53 | 53 | 0 | 1.64 | 1.80 |
| | | | 150 lbs. per acre | 1.73 | 2.01 |
| | | | 300 lbs. per acre | 2.29 | 2.03 |
| | | | 450 lbs. per acre | 2.05 | 2.24 |
| | | | Soybeans | | |
| Sand | 48 | 69 | 0.0 p.p.m. | 0.50 | 0.40 |
| | | | 1.0 p.p.m. | 0.78 | 0.42 |
| | | | 3.0 p.p.m. | 0.81 | 0.62 |
| | | | 5 0 p.p.m. | 1.00 | 0.68 |
| | | | 10.0 p.p.m. | 0.86 | 0.86 |
| | | | Soybeans | | |
| Solution | 48 | | 0.5 p.p.m. | 1.13 | |
| | | | 1.0 p.p.m. | 1.63 | |
| | | | 2.0 p.p.m. | 1.77 | |
| | | | 3.0 p.p.m. | 2.21 | |
| | | | 5.0 p.p.m. | 1.97 | |

*Pounds per acre are for muriate of potash.

The results of analyses of some other non-leguminous crops are given in Table 2. These results agree very well with those in the preceding table. In nearly all cases there is an increase in the percentage of potassium in the plant, particularly during the earlier periods of growth as the increment of potassium in the fertilizer becomes larger. It seems quite apparent from the results that the larger the amount of available potassium in the media the larger will be the percentage of potassium in the plant, although there may be a maximum absorptive capacity which was not reached in these experiments. As the plants become older, the percentage of potassium in the plants becomes less and the differences in potassium content of the plants from the different treatments become smaller. This would indicate that the supply of available potassium was not large enough to maintain the high level which the plants had attained in the earlier stages of growth. The full significance of this will be discussed in connection with some other data.

The results of the analyses on some leguminous crops are given in Table 3.

The differences are rather large, with the exception of the Hubam clover grown in the field. The probable reason for the lack of differences in the Hubam clover lies in the fact that the samples were nearly mature in both cases when taken and the excess potassium had probably been used up. That this explanation is probably correct is shown by the analyses given for the Hubam clover grown in culture solution. The plants growing in a solution containing 1 mgm of potassium per liter contained nearly twice as much potassium as those growing in a solution containing 0.5 mgm of potassium per liter. This is very interesting when it is noted that the latter concentration is all that is necessary to produce optimum growth of sweet clover. The differences in the cowpeas, both in solution culture and field plats, are very significant and corroborate the statement previously made that an increase in the amount of potassium supplied will be accompanied by a corresponding increase in the percentage of potassium in the plant in the early periods of growth. This is further supported by the results of the analyses of the soybean plants grown in sand and solution cultures and in field plats. In practically every case an increment in the amount of potassium has caused an increase in the percentage of potassium in the plants. While in some cases the increases are not extremely large, their consistency makes them significant.

A study of the yields produced from the various treatments in the different media reveals absolutely no correlation between the yields and the percentages of potassium in the plants. For that reason the yields have been omitted. In some instances the increases in yields have been accompanied by an increase in the percentage of potassium in the plant. However, whenever this condition was found, the increase in the percentage of potassium was usually several times as great as the increases in yields. In other cases the yields from the potassium treatments were smaller than the control treatments and yet the percentages of potassium in the plants were considerably greater.

Both of these conditions can be illustrated by using the results from the cowpeas in solution cultures and field plats (Table 3). The first condition named, *viz.*, an increase in yield accompanied by an increase in the percentage of potassium, is illustrated by the solution culture. There was very little difference in the yields from treatments of 1, 2, 3, and 5 p.p.m., yet the potassium in the plants from the application of 5 p.p.m. was nearly 70% greater than in those from the treatment of 1 p.p.m. In fact the yield from the 3 p.p.m. treatment was about 10% less than the 2 p.p.m. treatment and yet there was an 11% increase in the percentage of potassium in the plant.

The second case is exemplified by the cowpeas from the field plats. Based on the check or no treatment plats as 100% the yields at the first sampling were 100%, 102.1%, 92.8%, 92.8%, and 96.3%, respectively, for the check, no potassium, and the 150-, 300-, and 450-pound applications of muriate of potash. Potassium in the plant, however, shows an increase of from 2.25% in the check to 3.38% in the plants from the 450-pound application of muriate of potash. In other words, slight decreases in yields are accompanied by from 30 to 50% increases in the percentages of potassium in the plants.

It is very evident that the additional potassium in the latter cases was probably not needed for normal growth because it produced no increase in yield even in the presence of an abundant supply of the other elements. This is further proved by the yields at the time the B samples were taken. At this time the yields were 100%, 118.7%, 100%, 111.4%, and 115.6%, respectively, for the check, no potassium, and 150-, 300-, and 450-pound applications of muriate of potash. At the same time there was a very marked decrease in the percentage of potassium in the plants growing on the plats receiving applications of muriate of potash. In fact the decreases were so great in all cases except the heaviest potassium application that the percentages of potassium in the plants were not much larger than in the plants from the no treatment plats. These increases in yields accompanied by reductions in the percentage of potassium in the plants are evidence that the amounts of potassium found at the previous sampling were more than sufficient for the normal needs of the plants in the plats fertilized with different amounts of potassium. Moreover, the highest yield was secured from the plat receiving only nitrogenous and phosphatic fertilizers. The percentage of potassium in the plants from this plat was the same as in the plants from the no-treatment plats. This is also evidence that the larger amounts of potassium in the plants from the potassium-treated plats were caused by luxury feeding by the plants.

A similar analysis of the yields from the other crops reveals that the higher percentages of potassium found in nearly all cases where potassium was added were due to luxury feeding by the plants.

The finding of amounts of potassium in quantities larger than necessary for normal growth in plants grown under varied conditions would suggest that the additional potassium may play an important part in the nutrition of plants. A clew as to a probable use of this potassium may be obtained by constructing a graph as in Fig. 1, using the percentages of potassium given in Table 1 and the yields that correspond to those treatments at the time of sampling. Fig. 1 shows what took place during the growing season.

An inspection of the figure shows that there was a high initial concentration of potassium in the plants at an early stage of growth. The height of this level was in proportion to the amount of potas-

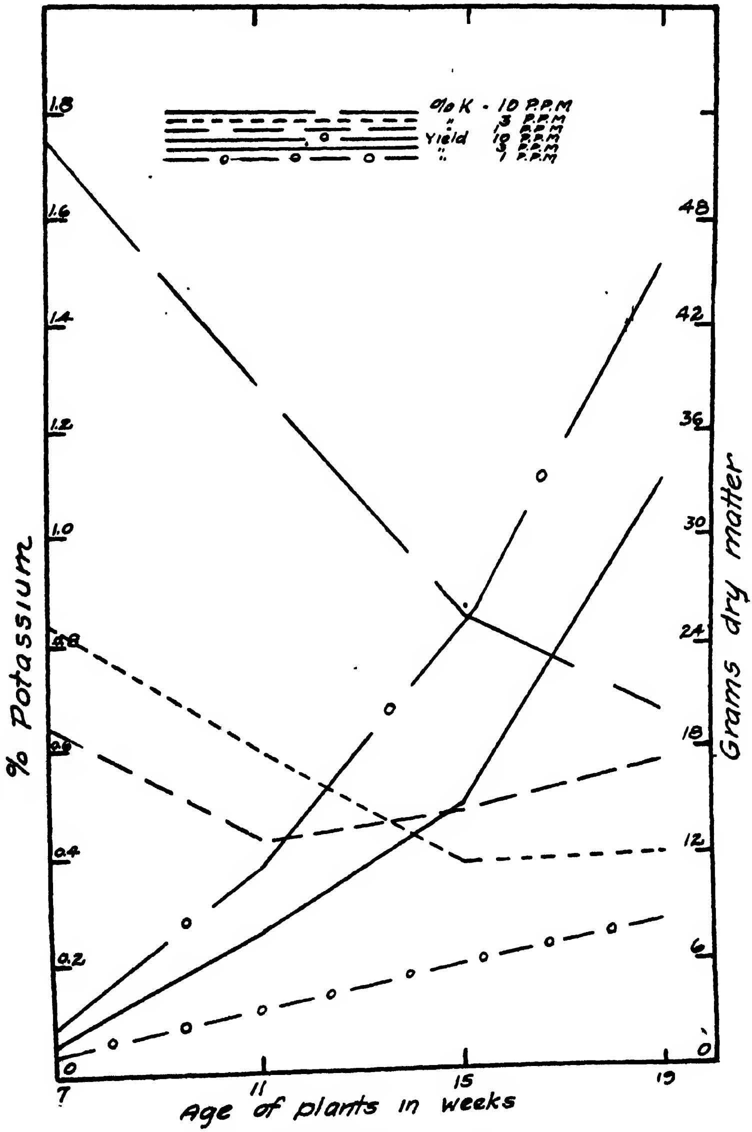


FIG. 1.—The relation between potassium content of oat plants and the amount of dry matter produced.

sium available to the plant. As the amount of growth increased, there was a very decided decrease in the potassium content of the plant. This could only mean that the supply of potassium available to the plant was not large enough to maintain the rapid rate of absorption which had evidently produced the high levels found at the earlier stages of development. Consequently, the plant was either suffering for lack of available potassium or else some of that already in the plant was being transferred to the growing regions and was being reutilized by the plant. The fact that growth took place very rapidly practically eliminates the probability that the plant was suffering from want of potassium. This leaves then the probability that the plant had taken up more potassium than was actually needed to perform normal life processes and had reutilized this potassium when the incoming supply became insufficient for its normal functions. That the latter explanation is correct is shown by data which are to follow.

The data were obtained from some experiments made to study the effect of potassium on certain physiological processes of the tomato plant, part of which were recently reported by the authors (6). Conclusive evidence was presented to demonstrate that tomato plants are able to translocate potassium from older to embryonic regions and reutilize the potassium in order to prevent starvation due to insufficient potassium.

Tomato plants were grown to from 6 to 8 inches in sand which received a nutrient solution rich in potassium. After transplanting one set received a full nutrition, while the other received an abundance of everything but potassium. In both experiments the plants were analyzed for both water-soluble and total potassium. In all cases all of the potassium was found to be water soluble. The amounts of potassium found per plant at different periods of growth are given in Table 4.

TABLE 4.—*Dry weight and potassium content of tomato plants grown with high and low potassium nutrition.*

| | Transplanting stage | | Blossom stage | | | | Fruiting stage | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Series 1 | | Series 2 | | Series 1 | | Series 2 | |
| | Series 1 | Series 2 | K | —K* | K | —K | K | —K | K | —K |
| K per plant in mgm. | 5 | 24 | 36 | 17 | 84 | 24 | 180 | 24 | 349 | 46 |
| Average weight per plant, grams | 0.13 | 0.52 | 0.97 | 1.56 | 1.57 | 1.14 | 5.40 | 4.33 | 7.44 | 3.16 |

*—K means no further addition of potassium after the plants were transplanted.

In one series it will be noted that there was a little more potassium per plant in the no-potassium treatment at the blossom stage than at the transplanting stage. A large part of this difference is due to the fact that the largest plants were transplanted in jars to receive no further additions of potassium in order to give them an opportunity to make as much growth as possible. The slight difference between the amounts present per plant at the fruiting stage and blossom stage may be due to translocation of the potassium from the roots to the stems. The roots of the no-potassium treatment contained only 0.3% potassium, while the roots from the full-potassium treatment contained 1.44% potassium. The amount of potassium per plant increased enormously at the different periods of growth in the full-potassium treatment.

A comparison of the average weight per plant in the two different treatments shows that in one case as much growth and in the other three-fourths as much growth were made on the low-potassium treatment as was made from the full-potassium treatment and yet there was only a small, if any, increase in the amount of potassium in the former, while there was a tremendous increase in the latter. The samples at the fruiting period showed this even more strikingly than the earlier samples. The weight of the plants nearly trebled and yet the average amount of potassium per plant remained practically the same in the low-potassium treatment. The results with the high potassium showed even larger increases in the amount of potassium per plant than had been found at the blossom period of sampling. Moreover, base leaves on the low-potassium treatment died without turning yellow. The greyish green color of the leaves was indicative of potassium starvation. The leaves contained 2.95% potassium when they were transplanted, whereas they contained only 0.38% potassium when they died.

A very plausible explanation of the results is that the potassium being water soluble was translocated and reutilized in the growing regions. These conclusions were confirmed by microchemical analyses. There was not sufficient potassium present in the base portion of the stems from the low-potassium treatment to produce crystals with a 10% solution of platinic chloride. The crystals in the low-potassium treatment were only found in the tip portion of the stems. Even in these sections very few crystals were obtained. On the other hand, potassium was found to be very abundant in all of the different regions of the stems from the high-potassium treatment.

## DISCUSSION OF RESULTS

There are at the present time several theories which are generally accepted to explain the manner in which plants absorb and utilize their mineral constituents. The chief difference in the theories lies in the explanation of the manner in which the plant food constituents are taken into the plant. The data in this paper are not presented in an attempt to clarify the situation with regard to the manner in which plants absorb their plant food constituents. In fact, none of the theories known to the writers will satisfactorily explain how the plants assimilate so much more potassium than apparently is necessary for normal growth. However, the data do offer an explanation of the manner in which plants may utilize potassium after it is taken up.

It has been shown that during the earlier stages of growth plants will take up large amounts of potassium apparently in excess of that necessary for normal growth. If the supply of potassium is then shut off or diminished, growth does not necessarily stop or slow up appreciably for some time. The plant may continue to make normal development for a considerable time by translocating and reutilizing the potassium in the plant. In fact the ability to translocate and reutilize the potassium is so great that it will be taken from older regions to growing regions in such quantities that the amount in the older regions will be insufficient for anywhere near normal processes and the cells will die from potassium starvation. The ability of plants to assimilate more potassium than necessary for normal growth and then reutilize this potassium has a very important bearing upon the principles of potassium fertilization.

How far the ability of plants to reutilize materials extends to other elements is not known, although there is evidence that it may apply to other elements than potassium. It has been reported by White (10) that much of the plant food constituents of cotton are taken up during the early stages of growth. He says,

"Stated roughly, approximately one-third of the total plant food is taken during the first period of 30 days in the life of the plant, terminating with the setting of the first form; a second third is taken during the second period of 30 days, terminating with the formation of the first bloom; by the termination of the third period of 60 days, with the opening of the first boll, 85 to 90% will have been taken, leaving only 10 to 15% to be added during the opening and maturing period of 90 to 100 days. Of the total dry matter of the plant, however, aproximately only one-eighth is produced during the first period; another eighth during the second period; one-fourth during the third period and one-half during the maturing period."

It does not seem probable that the 10 to 15% of the total plant food absorbed after the opening of the first boll would be sufficient to produce half of the dry weight, even though it were only used for maturing and ripening of the plant. There probably was some translocation and reutilization of plant food constituents, although from the results of other experiments (11) carried on at the same time White states that, "This would seem to indicate the important fact of the absence of a power in the plant to store food in any particular period of growth beyond the needs of the plant for that period."

An examination of the data, however, in regard to the plants receiving no potassium fertilizer reveals a situation very similar to that reported in this paper, namely, a decrease in the potassium content of the plant while the weight of the plant remains the same as that receiving potassium fertilization. There is also a very significant increase in the amount of nitrogen assimilated by plants receiving nitrogen and potassium fertilizers but no phosphorus fertilizer. Unpublished data reveals similar results with regard to nitrogen and calcium content of plants.

The "luxury assimilation" of potassium by plants may affect the present practice of potassium fertilization in several ways. Much of the potassium applied in the fertilizer may be taken up by the young plants and not fixed in very large amounts in the soil. When the supply of available potassium from the soil is used up the plant will make use of that in the plant. It will be necessary to adopt some method of maintaining a supply of available potassium in the soil as there may be less residual effect than formerly thought. It may be possible to side- or top-dress crops with potassium after signs of deficiency are observed and secure profitable results.

To illustrate the first case let us consider what might happen when the potassium is applied shortly before planting. Some of the potassium will undoubtedly unite with the base exchange complex the same as has always been maintained. However, this does not remove it from the sphere of the plant influence, for according to Magistad (8) this material is easily hydrolyzed and would therefore be readily available to the plants as the supply of potassium in the soil solution was diminished. In fact, Breazeale (5) found that after practically all the replacable bases had been replaced by potassium six crops of 100 wheat seedlings completely depleted the available potassium from a 50-gram sample of soil. Consequently, as the plants grow the supply of available potassium will be greatly diminished due to rapid hydrolysis of potassium from the exchange

complex and the amount of potassium in the soil solution will be smaller than required for normal growth of the plants. While it might be assumed that the base exchange complex might furnish sufficient potassium to keep the plant functioning normally, the fact that it is easily hydrolyzed would suggest that the supply of exchangeable potassium would have been greatly reduced. In other words, when a crop is feeding heavily upon potassium, as it does with luxury feeding, the supply of available potassium may be practically exhausted in a short time. The same condition would exist in soils which had been cropped for some time without the addition of potassium fertilizer.

The importance between the exchangeable potassium and plant growth has also been emphasized by Martin (9) who found that after 12 years of continuous cropping with barley 32% of the original exchangeable potassium had been removed, and that this potassium constituted 80% of that found in the crops. Moreover, he reports that two crops of barley with a 10-year interval of fallow treatment between them had removed 15% of the exchangeable base and that this amount was 68% of that found in the plants.

It has been shown by Ames and Simon (1) and by others that the amount of potassium which may be extracted from soil by water decreases very rapidly after the first extraction, even in soils which have been fertilized with potassium fertilizers for a number of years, and suggests that the supply of available potassium would be very rapidly reduced by heavy feeding of plants.

The situation under field conditions would be, therefore, that the supply of available potassium in the soil solution would not be sufficient to meet the needs of the plant. Consequently, as the growing regions of the plants needed more potassium, the plants would translocate some from the older regions to the growing regions and the plant would continue to make normal growth, even though the supply of available potassium in the soil solution was lower than that required for normal growth. This contention is also supported by an experiment conducted in the greenhouse. Cotton plants growing in a solution containing potassium maintained at a concentration of 0.5 mgm per liter were transferred to a solution containing no potassium when they were about 15 inches high. After growing for two months in the potassium-free solution they did not show any apparent physiological disturbance and appeared to be making normal growth.

With the above statements in mind it would appear that practically normal growth may be produced for some time if potassium, due to

an insufficient supply, becomes the only factor limiting the amount of growth which might be produced. When physiological disturbances due to potassium deficiency occur, it would be a sign that the amount of available potassium in the soil was practically nil. In order to produce anywhere near normal crops after potassium deficiency signs appear, it would be necessary to make annual additions of potassium fertilizers as the process of building up a supply of available potassium is a long and difficult one. These statements are in accord with present fertilizer practices in which very frequent applications of potassium are applied to potassium-deficient soils.

The theory presented indicates the importance of adopting some system, such as the use of green manure, to maintain an adequate supply of available potassium. A similar suggestion was made by Blair (4) who suggested the use of soybeans as a means of taking up the available potassium and returning it to some other crop.

The ability of plants to take up large amounts of potassium very rapidly suggests that side-dressings of potassium fertilizers may be applied with good results when signs of potassium deficiencies become apparent.

The writers do not mean to imply that luxury feeding on potassium with its subsequent translocation is the only way in which plants utilize their potassium. It is recognized that even when the concentration of potassium is smaller than that required for normal growth there will still be absorption of potassium from the soil solution. However, it is believed that under most conditions the translocation of potassium in plants may and does in many cases prevent potassium starvation which would cause smaller yields.

## SUMMARY

Analyses were made to determine the potassium content of plants grown in soil, sand, and solution cultures which had received applications of different amounts of potassium. A theory for the utilization of potassium is developed from the data presented. The application of the theory to fertilizer practices is discussed. The results may be summarized as follows:

1. Plants absorb considerable more potassium during the early periods of growth than is necessary for the normal processes of growth. This applied to the crops studied, including alfalfa, Hubam clover, cowpeas, soybeans, oats, wheat, Sudan grass, corn, cotton, and tomatoes.

2. The potassium in the tomato plant is practically all water soluble.

3. Potassium can be translocated within the plant and reutilized to prevent starvation when the supply of available potassium is insufficient to supply the needs of the growing regions.

4. It is suggested that the luxury consumption of potassium followed by translocation and reutilization of the potassium in the plant is an important process in the assimilation of potassium by plants.

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# THE INFLUENCE OF THE COMBINE ON AGRONOMIC PRACTICES AND RESEARCH[1]

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The combine, or combined harvest-thresher, which was not found east of the Rocky Mountain states prior to the world war, is now used in nearly every grain-growing state in the Union. About 21,000 combines were manufactured in the United States in 1928. Within a period of 10 years in Kansas combine harvesting developed from an initial trial to the present situation in which more than half of the enormous wheat crop of that state is harvested with combines. The eastern advance of the combine did not stop at the border of the extensive wheat-growing region, but hundreds of the machines are now found on farms in the corn belt and eastern states. A combine has been used as far east as Delaware during the past four seasons.

Combines have been used in the Pacific Coast states since the early eighties. For many years, however, the statement was made and believed by agronomists, farmers, and others familiar with cereal production that the combine would not be practicable for harvesting east of the Rocky Mountains because the grain would neither stand long enough nor be dry enough for combining. This advice was given freely and was almost universally accepted. The scarcity of harvest hands during the war, however, awakened interest in methods of reducing labor. As a result a few venturesome but uninformed farmers in the Great Plains, who lacked the knowledge that "combines could not be used," bought the machines and were well pleased with the new method of harvesting. The development of the small prairie-type machine greatly augmented the success of the combine in the Great Plains.

It is to be regretted that in most states agronomists have permitted the farmers to lead the way in demonstrating the efficacy and economy of combine harvesting and in overcoming the difficulties encountered with the new method.

Cooperative investigations[3] of combine harvesting in a total of 13 states during the past three years and observations in other states

[1]Contribution from the Office of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture, Washington, D. C. Received for publication February 28, 1929.

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[3]These investigations were conducted by the Bureaus of Agricultural Economics, Plant Industry, and Public Roads, of the U. S. Department of Agriculture, in cooperation with the agricultural experiment stations of Texas, Oklahoma, Kansas, Nebraska, Montana, North Dakota, South Dakota, Minnesota, Illinois, Indiana, Pennsylvania, Virginia, and Georgia.

show how the combine has influenced agronomic practices and also reveal many ways in which it is likely to influence the practices of the future. The purpose of this article is to call attention to some of the agronomic problems, many of them unsolved, which have arisen with the increasing and widespread use of the combine for harvesting many crops.

Combines have been used for harvesting wheat, oats, barley, rye, flax, rice, grain sorghums, buckwheat, emmer, sweet clover, red clover, mammoth clover, alsike clover, alfalfa, soybeans, timothy, millet, and cowpeas.

## TYPE OF FARMING

The use of the combine with the accompanying power-farming equipment has decreased the need for feed crops and has increased the proportion of most of the grain and seed crops which can be harvested with the combine. Diversified farming has declined in some sections because the increased efficiency in grain growing has made other crops relatively less profitable. Crops, such as small grains and soybeans, which can be harvested readily with the combine are partly replacing corn and hay which require more laborious methods of harvesting. New systems of crop rotation and soil fertility conservation may need to be developed to fit into the modern scheme of mechanized farming.

Probably no state in the Union is exempt from a consideration of combine harvesting because of its high rainfall or rough lands. The use of the combine is more limited by the type of farming than by climatic or topographic conditions. A combine should not be purchased unless 100 to 150 acres are to be cut each year. The machine, therefore, will be confined largely to farms on which considerable acreages of grain or other seeds are to be harvested. Combines have been used successfully on large farms in many eastern states. Grain crops on small farms in the East probably will continue to be cut with binders, however, unless custom combining becomes more generally practiced. Considerable custom work is now being done with combines and some machines are owned or operated in partnership, but cooperative ownership of combines is very rare. Combines will not be economically feasible where fields are small, scattered, and rather inaccessible or too rough for machine operations.

## SIZE OF FARM

Investigations in Kansas (1)[4] have shown that rather large farm units permit the most efficient use of the combine. In the Great

[4]Reference by number is to "Literature Cited," p. 773.

Plains area at least 400 to 600 acres of grain must be grown in order to utilize fully the seasonal capacity of the combine and the tractor required to pull it. The ultimate result of this situation will be that one farmer will till the land formerly operated by two or three farmers, with a consequent reduction in the farm population. This has already taken place in some sections of Oklahoma and Kansas. Readjustments should be anticipated in other sections also.

Combines and other power equipment can be operated with less wasted time in large fields than in small fields. This frequently results in fences being removed to enlarge the fields. Large fields are not absolutely necessary for combine operation, however, because the machines can turn a square corner within the space of the previous swath.

## PROMPT TILLAGE

One of the chief advantages of the combine from the agronomic standpoint is that it clears the fields at once and permits prompt tillage of the stubble land. Tillage immediately after harvest probably is the principal factor in the successful growing of winter wheat continuously on the same land in the southern half of the Great Plains. When damp weather at frequent intervals interferes with combine harvesting, the tillage of the stubble land sometimes can be kept up almost even with the harvesting. Sometimes the land from which the crop was harvested during the day is plowed, disced, or listed during the succeeding night. Yields of wheat thus may be increased after combines are introduced because of more timely tillage operations.

## DOUBLE CROPPING

Prompt working of the land following combine harvest also permits the sowing of a late crop, such as soybeans, on the grain land, thus producing two crops a year in the southern states. The soybean crop can then be harvested with a combine in time to sow the land back to grain. Two crop residues of a legume and a nonlegume crop thus are returned to the soil each year. This system is now being attempted in at least three states in the South, and promises to revolutionize existing farming methods. The effects of this scheme upon soil conditions and the fertilizer requirements are yet to be determined.

## ORGANIC MATTER

The concern which has been felt in regard to the loss of organic matter from the soil in grain farming may be largely relieved by the advent of combine harvesting. Excessive quantities of organic

matter not easily rotted under dry-land conditions, are a more serious problem now. Most of the combines in the central and eastern states are equipped with straw spreaders which distribute the straw rather uniformly over the ground. The entire crop residues, varying in quantity from 0.5 to 2 tons of air-dry material per acre thus are returned to the soil. If the growth of straw is too heavy it sometimes is burned in order to facilitate plowing or to prevent excessive drying or denitrification of the soil. Burning of the straw in most seasons is practiced generally only in parts of Montana and the Pacific Coast states.

Much investigation remains to be done both on the physical, chemical, and biological effects of turning under and of burning straw, and on the methods of incorporating straw and stubble with the soil. The rate and nature of the decay of straw under various climatic and soil conditions also needs to be studied.

## USE OF STRAW FOR FEED

With the exception of that used for bedding, most of the cereal straw produced in the western half of the United States is wasted, but considerable quantities are fed to livestock in the East. The need of straw for feed frequently is advanced as an objection to combine harvesting in the eastern half of the United States. There is some basis for this objection, but the loss is no more serious than the waste of corn stover where the ears of that crop are husked from the standing stalks. If in the future corn stalks are cut up as a means of checking the corn-borer, there probably will be a surplus of roughage in some sections, and small-grain straw need not be saved. In the eastern states, where nearly all of the grain straw is preserved, considerable areas of crops suitable for forage, such as rye and cowpeas, are plowed under for green manure. Crop residues turned under probably can be substituted for the crops used as green manure and the latter can be harvested for feed.

Fortunately the straw from the combine can be saved by some additional labor. One method is to remove the straw spreader from the combine and drop the straw in windrows where it can be gathered with a hay loader. Another method is to use a dumping apparatus which drops the straw and chaff into piles which can be picked up and hauled later. Still another method is to mow the stubble and rake and bunch the straw after harvest.

Agronomic problems requiring solution are the determination of (a) the relative values of crop residues and green manure crops for both feed and fertilizer; and (b) the advantages of hauling straw from

the field to the barnyard, incorporating it with manure, and then returning it to the land as compared with leaving the straw in the field to decay on or within the soil.

## CROP LOSSES

Harvesting and threshing losses were believed to be much greater with the use of the combine than if the crop had been harvested with a binder, until extensive determinations (2, 3) demonstrated that binders and separators usually caused greater losses of grain than combines.

Savings in grain as a result of combine harvesting, amounting on the average to less than a bushel per acre, usually are not large enough to affect the farm income appreciably. Occasionally, however, fields are harvested with combines where the crop is poor or badly lodged which would have been abandoned if a binder were the only harvesting machine available. Where the cereal stems are likely to crinkle down or break over soon after maturity the losses from combining may be expected to equal or exceed those from binder harvesting. When the weather is damp, crinkling may take place rather soon after the maturity of the crop. Oats are more susceptible to crinkling than barley and barley is more susceptible than wheat or rye. Oats crinkle easily after maturity even in dry sections. Most grain sorghums go down soon after maturity or after a frost, while flax stands erect for long periods.

## CROP VARIETIES

Until recently the popular idea has been that only certain stiff-strawed, non-shattering varieties were suitable for combine harvesting. Many believed that such varieties were grown in, and were suitable for, only the Pacific Coast states. For many years, however, hard red winter and hard red spring wheats, the leading classes in the Great Plains, have been grown in some sections of the Pacific Northwest and have been harvested successfully with combines. Observations on the shattering of wheat varieties show that the hard red winter and durum varieties and most of the wheats of other classes are not likely to cause appreciable shattering losses. Only a few varieties of soft red winter wheat will shatter noticeably when let stand for several weeks after maturity. The shattering propensities of all new varieties should be determined before they are distributed.

Studies of oat varieties (4) show that, although a serious problem, shattering in general is less frequent than crinkling. There are important differences in the rate of shattering among the varieties

which should be determined in every oat region. Lodged oat plants may shatter less than erect plants. Some varieties of barley, such as Manchuria, shatter much more easily than the Coast variety which is largely grown west of the Rocky Mountains. Some readjustments of distribution of oat and barley varieties may be necessary.

There are important differences in the susceptibility of different cereal varieties to lodging before the grain is matured. Lodging is a serious handicap to any method of harvesting, but lodged grain can be harvested more successfully with the combine than with the binder.

Crinkling or breaking over of the straw is a greater handicap than lodging or shattering in combine harvesting, because this usually occurs after the period of binder harvest. Nearly all varieties of wheat, oats, and barley seem to be susceptible to crinkling, but any differences in the tendency to crinkle should be considered in selecting varieties for combining. Crinkled grain can be harvested with a combine, but the losses are greater than if the crop had been harvested while still erect.

In the future, grain varieties will be tested for shattering, lodging, and crinkling along with such agronomic characters as yield, quality, earliness, and disease resistance. Recent experiments indicate that losses from shattering when ripened grain stands for extended periods sometimes are larger than had been estimated from previous observations.

## MOISTURE CONTENT OF GRAIN

Tests have shown that combined grain, on the average, contains more moisture than that harvested by other methods. The moisture content need not be higher, however, if harvesting is done only when the crop is in a proper condition. Moisture tests so far devised are not suitable for general farm use. Reliable plant indicators of moisture content are needed. More should be learned regarding the effect of weather on the condition of the crop.

A delay of 7 to 14 days after the crop is ready for the binder usually is necessary before combining should begin, and the grain also must be permitted to dry after each dew or rain. Reports from farmers show that damp grain from the combine sometimes has been sold at a discount, but that, on the average, the combine operator receives nearly as much as does the farmer who harvests with a binder. The saving in costs in combine harvesting will absorb a considerable discount in the price received for the grain, but this discount usually is unnecessary if proper attention is given to the time of harvesting. Grain crops sometimes must stand for considerable time in order to be harvested during dry weather.

## WEEDS

Green weeds cause considerable difficulty in harvesting and threshing grain with a combine by increasing threshing losses, clogging the machine, and increasing the moisture content of the threshed grain. Weeds cause the most trouble when harvest is delayed by wet weather during which time the weeds make rapid growth. Ordinary combining will not be very successful where green weeds are abundant, but the use of the windrow method promises to solve the weed problem. This method consists of the use of a cutting platform which deposits the cut grain on the stubble in a windrow or swath. After the cut material has cured in the windrow a combine equipped with a "pick-up" attachment gathers up and threshes the grain. The dry weeds do not increase the moisture content of the grain nor interfere with threshing.

Clean fields will greatly facilitate combine harvesting and expanded programs for weed eradication will not be out of place.

## ECONOMIC FACTORS

The use of the combine on large acreages reduces the total cost of harvesting grain, as compared with a binder and hired separator, by nearly $2 per acre (3).

This saving in harvesting cost permits the cropping of marginal lands which were formerly considered unprofitable. Large acreages of virgin sod in the semi-arid southwestern portion of the Great Plains have been broken and sown to wheat during recent years. The combine, together with the tractor and large tillage implements, has thus permitted the economical production of wheat in sections which until recently were considered unfitted for successful grain production. This expansion furthermore has taken place during a period of agricultural depression.

There apparently already is a keen competition in wheat growing between the southwestern Great Plains and other wheat-producing areas, but the greatest progress has been made where combines and other large-scale equipment are used. Some disturbance in the distribution of crop acreage as a result of economic advantages from extensive methods of production may be anticipated.

## CONCLUSIONS

Extensive use of the combine probably will result in a decrease in diversfied farming and increases both in the size of farms and fields and in the practice of early tillage. The combine also will facilitate the practice of double cropping in some sections.

The use of the combine is limited much more by the type of farming than by climatic or topographic conditions.

Combining probably will largely solve the problem of organic matter in the soil in the region east of the Rocky Mountains by immediately returning the crop residue to the land if needed.

The usual loss of straw for feed in combining probably will be compensated by a decrease in the growing of green-manuring crops. If straw is desired for feed, it can be saved by some additional labor.

Crop varieties susceptible to lodging can be harvested more efficiently with a combine than with a binder. Only a few varieties of wheat will ever shatter enough to cause appreciable losses, but most varieties of oats and some varieties of barley will shatter unless harvested as soon as they are ripe enough to combine.

Crinkling or breaking over of the stalks after maturity frequently occurs when the season is damp and harvesting is delayed considerably. Harvesting losses are increased considerably by crinkling.

Combined grain will contain excessive moisture unless harvesting is done only when the crop is in proper condition, with special care to permit drying of the dew or rain.

Green weeds are a serious handicap to combining, but weedy crops can be combined satisfactorily by the windrow method.

The use of the combine and accompanying large-scale power farm equipment has made possible the economical growing of wheat on what formerly were considered marginal lands.

Agronomic problems concerning cropping systems, rotations, soil fertility, crop residues, and crop varieties, which have arisen since the combine has come into general use, are suggested for investigation.

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# COMPARATIVE ACRE YIELDS OF SUGAR BEET VARIETIES IN THE UNITED STATES AND CANADA DURING 1928[1]

GEORGE STEWART[2]

During the growing season of 1928, there were conducted in the United States and Canada about 24 or 25 comparative yield tests with sugar beet varieties. A few of these were conducted by large sugar companies whose policy is not to make their data available. At the time of writing, 20 sets of data from tests, fully to somewhat replicated and checked, have been obtained. Of these, one was in Canada, and nine were conducted at state experiment stations of the United States as follows: Prince Edward Island, 1; Minnesota, 3; North Dakota, 1; Kansas, 1; Wyoming, 1; Utah, 2; and California, 1.

Four of the tests were conducted by federal agencies located in the following states: Michigan (U. S. D. A. Sugar Plant Investigations), South Dakota (U. S. D. A. Western Irrigation Agriculture), Colorado (U. S. D. A. Sugar Plant Investigations), and Oregon (U. S. D. A. Forage Plant Investigations).

Six tests were conducted by various sugar companies in the following states: Iowa (American Beet Sugar Company), 1; South Dakota (Utah-Idaho Sugar Company), 1; Colorado (American Beet Sugar Company), 1; Idaho (Amalgamated Sugar Company), 2; and Utah (Amalgamated Sugar Company in cooperation with Utah Experiment Station,) 1.

In addition to these replicated or checked tests, there were about a dozen others which lacked checks or which were not replicated. These are not included.

It is to be regretted that the data for the other tests were not available. It is hoped, however, that these 20 tests, distributed as they are in eastern Canada and from Michigan to California, will give some suggestion as to varietal behavior. All important sugar beet regions, except Nebraska and Montana, are represented by at least one test. Additional tests in the territories not represented

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[2]Agronomist. The author gratefully acknowledges his indebtedness to the several state and federal experiment stations as well as to those sugar beet companies which have contributed to this article by placing certain data in his hands, and permitting their use in this study. A considerable part of the data involving Russian varieties has been made available by the Amtorg Trading Corporation, a Russian importing company. Credit for the station or company and for the man in charge of each trial is made in the text immediately preceding the tabular presentation of each set of data.

would have added interest. Unfortunately, the lists of varieties differ too widely to permit direct comparison. Perhaps something approaching more nearly a uniform test may later be developed.

## EXPERIMENTAL DATA

In order to eliminate so far as possible any emphasis of one set of data over any other, all sets of data for each state are presented together, beginning with Michigan and going westward to California. In each region the order is from north to south.

### MICHIGAN (U. S. DEPT. OF AGRICULTURE)

In 1928, J. G. Lill of the U. S. Dept. of Agriculture Sugar Investigations grew 50 varieties of sugar beets on the O'Keefe farm of the Michigan Sugar Company. The varieties were grown in single rows which extended at right angles across eight different soil treatments. The soil treatments consisted of fall and spring plowing for plowing depths of 4, 6, 8, and 10 inches. Every third row was a check variety. The beets were harvested separately for each variety and each plowing treatment. Thus, for each variety there were sets of figures which were regarded as replications. The beets were not irrigated. The summary data for this test are given in Table 1.

The Michigan varieties are arranged in order of the acre yields of sugar. Of the highest yielding 26 varieties, 21 gave odds of from 30:1 to 1000:1 by "Student's" method that they were higher yielders than the unnamed check which was grown every third row. These varieties with odds of at least 30:1 for higher yields in order of sugar production, together with their yielding order and their relative sugar yield when the checks are called 100, are as follows:

| | | |
|---|---|---|
| 1. | UDYCZ "B" | 155 |
| 2. | Mayzol—Granum "Plenno" | 150 |
| 3. | Bielotzerkov (Russian) | 141 |
| 4. | Vierchniatchka (Russian) | 139 |
| 5. | Heine Original | 137 |
| 6. | Uladovka (Russian) | 135 |
| 7. | Buszczynski's Neo Maximale | 135 |
| 8. | Buszczynski's Productive | 134 |
| 9. | UDYCZ "A" | 131 |
| 10. | Rimpau I | 131 |
| 11. | Braune Elite | 127 |
| 12. | Schreiber's "S. K. W." | 126 |
| 13. | Dippe's "G. D. E." | 125 |
| 14. | S. W. H. N | 125 |
| 15. | R. and G. "ZZ" | 121 |
| 16. | Strube Original Schlanstedt | 120 |
| 17. | August Knoche "Z" | 119 |
| 18. | Otto Dippe | 119 |
| 20. | Buszczynski's Prod. S. E | 118 |
| 23. | Hilleshög | 116 |
| 26. | August Knoche "E" | 114 |
| | Check, variety not named | 100 |

### MINNESOTA (STATE EXPERIMENT STATION)

A. C. Arny of the Minnesota Station conducted tests of 19 varieties of sugar beets at University Farm, at Waseca, and at Crookston.

TABLE 1.—*Acre yield of roots, percentage sugar, purity coefficients, and acre yield of sugar for 50 varieties of sugar beets grown during 1928 near Saginaw, Mich.*

| Variety | | Acre yield of roots in tons | Sugar content % | Purity % | Acre yield of sugar in pounds |
|---|---|---|---|---|---|
| UDYCZ "B" | P† | 8.791 | 18.54 | 89.04 | 3,287 |
| Mayzol-Granum "Plenno" | P | 8.705 | 18.44 | 90.39 | 3,172 |
| Biolotzerkov "E" | P | 8.541 | 17.56 | 88.15 | 2,992 |
| Verchiatchka "N" | P | 8.131 | 18.19 | 88.23 | 2,951 |
| Heine Original | C† | 8.028 | 18.25 | 88.27 | 2,898 |
| Uladovka "E" | P | 8.141 | 17.53 | 87.97 | 2,865 |
| Buszczynski's Neo Maximale | C | 7.545 | 18.86 | 89.69 | 2,864 |
| Buszczynski's Productive | C | 7.563 | 18.74 | 88.93 | 2,841 |
| UDYCZ "A" | P | 7.549 | 18.38 | 88.36 | 2,778 |
| Rimpau I | P | 8.008 | 17.36 | 87.73 | 2,774 |
| Braune Elite | P | 8.010 | 16.89 | 87.19 | 2,680 |
| Schreiber's "S. K. W." | C | 7.451 | 17.91 | 88.80 | 2,676 |
| *Dippe's "G. D. E." | P | 7.757 | 17.17 | 88.75 | 2,655 |
| S. W. H. N | C | 7.311 | 17.96 | 88.78 | 2,640 |
| R. and G. "ZZ" | P | 6.793 | 18.83 | 88.71 | 2,558 |
| Strube Original Schlanstedt | C | 7.146 | 17.94 | 89.28 | 2,544 |
| August Knoche "Z" | P | 6.985 | 18.19 | 87.56 | 2,519 |
| Otto Dippe | C | 7.320 | 17.38 | 88.05 | 2,514 |
| R. and G. "Old Type" | P | 7.088 | 17.74 | 88.44 | 2,509 |
| *Buszczynski's Prod. S. E | P | 6.599 | 19.09 | 89.39 | 2,489 |
| Albert Griesing-Sporen | P | 7.329 | 17.22 | 87.41 | 2,498 |
| Hartman's "Glostrup" | C | 7.413 | 16.60 | 86.02 | 2,463 |
| Hilleshög | C | 6.744 | 18.30 | 88.45 | 2,450 |
| Delitzscher | C | 6.955 | 17.60 | 88.38 | 2,442 |
| Zapitol | C | 6.857 | 17.83 | 89.04 | 2,437 |
| August Knoche "E" | P | 7.046 | 17.23 | 87.71 | 2,419 |
| *Canadian Grown | P | 6.759 | 17.88 | 88.33 | 2,417 |
| Ivanovka "N" | P | 6.708 | 17.93 | 88.49 | 2,403 |
| Z. and C. "R. W." | P | 6.290 | 18.99 | 89.15 | 2,388 |
| Granum "Cukrowe" | P | 6.264 | 18.62 | 88.77 | 2,359 |
| Schreiber's "S. S." | C | 6.535 | 17.75 | 89.15 | 2,296 |
| *Dippe's "G. D. R. K." | P | 6.576 | 17.23 | 87.88 | 2,280 |
| Braune "New Type" | P | 6.503 | 17.43 | 88.58 | 2,269 |
| R. and G. "Pioneer" | C | 6.166 | 18.20 | 89.43 | 2,244 |
| R. and G. "Extreme Pioneer" | P | 6.243 | 18.12 | 86.99 | 2,265 |
| *Vilmorin Brand | P | 6.463 | 17.29 | 87.60 | 2,234 |
| Z. and C. "R. S." | P | 5.879 | 18.90 | 89.30 | 2,220 |
| Braune Commercial | C | 6.617 | 17.05 | 86.90 | 2,219 |
| Janascz "A. J. I." | P | 5.954 | 18.60 | 87.36 | 2,219 |
| Wohanka "W. Z. R." | C | 6.035 | 18.19 | 88.51 | 2,204 |
| Horning | C | 6.095 | 17.88 | 88.02 | 2,187 |
| Sebline | P | 5.950 | 17.89 | 88.95 | 2,146 |
| Motto | C | 5.950 | 18.09 | 89.10 | 2,141 |
| Average of Controls | P | 5.982 | 17.72 | 88.10 | 2,116 |
| Frederiksen's "Eagle Hill" | C | 5.941 | 17.29 | 86.35 | 2,082 |
| *Dippe's "G. D. Z." | P | 5.771 | 17.75 | 87.32 | 2,053 |
| Rimpau II | P | 5.726 | 17.64 | 88.27 | 2,004 |
| R. and G. "Normal Original" | C | 5.107 | 17.26 | 88.07 | 1,776 |
| Dippe's "G. D. W. I." | C | 4.801 | 17.96 | 87.98 | 1,733 |
| Dobrovice | C | 4.723 | 17.65 | 88.45 | 1,683 |
| *Royal Dutch Pedigree | C | 4.443 | 17.99 | 87.73 | 1,586 |

*Seed was from the 1926 crop.
†P = Sample from producer; C = From commercial seed.

TABLE 2.—*Acre yield of roots, percentage sugar, purity, and acre yield of sugar of 19 sugar beet varieties grown in Minnesota, 1928.*

| Variety | Acre yield of beets in tons | Purity % | Acre yield of sugar in pounds | Sugar content % |
|---|---|---|---|---|
| **University Farm** | | | | |
| Pioneer (R. and G.) | 14.72 | 87.0 | 5,403 | 18.3 |
| Extreme Pioneer (R. and G.) | 13.66 | 86.6 | 4,942 | 18.1 |
| Old Type (R. and G.) | 14.29 | 82.6 | 4,993 | 17.5 |
| New Type (R. and G.) | 15.51 | 86.3 | 5,581 | 17.9 |
| Original (R. and G.) | 15.99 | 86.5 | 5,676 | 17.7 |
| Dippe W. S | 16.57 | 85.4 | 6,032 | 18.2 |
| Dippe E | 16.60 | 85.8 | 5,469 | 16.5 |
| Delitzscher E | 17.05 | 88.1 | 5,800 | 17.0 |
| Schreiber S. B | 15.86 | 87.4 | 5,441 | 17.2 |
| Strube E | 14.29 | 83.7 | 4,704 | 16.5 |
| Braune | 13.43 | 85.3 | 4,273 | 15.9 |
| Flat Foliage | 15.81 | 85.9 | 5,439 | 17.2 |
| Janascz | 13.71 | 88.5 | 5,261 | 19.2 |
| Dobrovice | 13.18 | 86.3 | 4,620 | 17.5 |
| Wohonka | 14.27 | 87.4 | 5,197 | 18.1 |
| Zapotil | 13.30 | 82.0 | 4,529 | 17.1 |
| Ivanovka (Russian) | 13.43 | 87.9 | 4,689 | 17.5 |
| Bielotzerkov (Russian) | 12.62 | 87.8 | 4,512 | 17.9 |
| Uladovka (Russian) | 12.43 | 85.1 | 4,464 | 18.0 |
| **Waseca** | | | | |
| Pioneer (R. and G.) | 12.66 | 89.9 | 5,162 | 20.4 |
| Extreme Pioneer (R. and G.) | 12.64 | 92.0 | 5,262 | 20.8 |
| Old Type (R. and G.) | 12.30 | 89.9 | 5,340 | 21.7 |
| New Type (R. and G.) | 12.30 | 89.7 | 5,197 | 21.1 |
| Original (R. and G.) | 14.98 | 89.5 | 6,392 | 21.8 |
| Dippe W. S | 12.81 | 91.0 | 5,499 | 21.5 |
| Dippe E | 13.42 | 88.5 | 5,461 | 20.3 |
| Delitzscher E | 14.62 | 88.8 | 5,922 | 20.3 |
| Schreiber S. B | 14.56 | 88.6 | 6,056 | 20.8 |
| Strube E | 13.71 | 88.9 | 5,746 | 21.0 |
| Braune Elite | 15.06 | 88.7 | 6,217 | 20.6 |
| Flat Foliage | 13.15 | 89.1 | 5,834 | 22.1 |
| Janascz | 13.27 | 89.1 | 5,942 | 22.4 |
| Dobrovice | 12.85 | 88.2 | 5,191 | 20.2 |
| Wohanka | 12.91 | 86.4 | 5,413 | 21.0 |
| Zapotil | 12.66 | 87.7 | 5,117 | 20.2 |
| Ivanovka | 14.40 | 88.5 | 6,084 | 21.1 |
| Bielotzerkov | 15.04 | 86.8 | 5,938 | 19.8 |
| Uladovka | 14.59 | 89.6 | 5,999 | 20.6 |
| **Crookston** | | | | |
| Pioneer (R. and G.) | 8.73 | | 2,874 | 16.5 |
| Extreme Pioneer (R. and G.) | 10.97 | | 3,632 | 16.5 |
| Old Type (R. and G.) | 10.36 | | 3,263 | 16.6 |
| New Type (R. and G.) | 9.85 | | 3,296 | 16.8 |
| Original (R. and G.) | 9.66 | | 3,213 | 16.7 |
| Dippe W. S | 10.68 | | 3,867 | 18.1 |
| Dippe E | 10.79 | | 3,476 | 16.0 |
| Delitzscher E | 11.14 | | 3,333 | 15.0 |
| Schreiber S. B | 10.59 | | 3,469 | 16.4 |
| Strube E | 9.83 | | 3,503 | 16.7 |
| Braune | 11.15 | | 3,390 | 15.3 |
| Flat Foliage | 9.51 | | 3,094 | 16.3 |
| Janascz | 9.35 | | 3,368 | 18.0 |
| Dobrovice | 9.61 | | 3,107 | 16.1 |
| Wohanka | 10.23 | | 3,523 | 17.6 |
| Zapotil | 7.83 | | 2,634 | 16.8 |
| Ivanovka | 9.36 | | 3,198 | 17.1 |
| Bielotzerkov | 10.43 | | 3,271 | 15.7 |

The plats were four rows wide, 132 feet long, and were replicated three times. At University Farm the soil is a sandy loam and not very uniform. At Waseca it is heavier and more uniform. At Crookston it is deep, black, very heavy, and rather poor as to uniformity. These tests were non-irrigated. A summary of the data from these three tests is given in Table 2.

At University Farm 7 of the 19 varieties yielded more than 5,400 pounds of sugar to the acre. Though no variety was repeated frequently enough to be called a check, Pioneer is here so regarded. The acre yield of sugar of the leading seven varieties when Pioneer is given the base value of 100 are as follows:

1. Dippe W. S. ........... 112
2. Delitzscher E .......... 107
3. Original (R. and G.) .... 105
4. New Type (R. and G.).. 103
5. Schreiber S. B ......... 101
6. Flat Foliage[3] .......... 101
7. Pioneer R. and G ...... 100

At Waseca 8 of the 19 varieties yielded more than 5,900 pounds of sugar to the acre. Regarding Pioneer as a check, these eight varieties gave the following relative yields of sugar:

1. Original (R. and G.) .... 124
2. Braune Elite .......... 120
3. Ivanovka (Russian) .... 118
4. Schreiber S. B ......... 117
5. Uladovka (Russian) .... 116
6. Janascz (Polish) ....... 115
7. Bielotzerkov (Russian).. 115
8. Delitzscher E .......... 115
9. Pioneer (R. and G.) .... 100

At Crookston 5 of the 19 varieties produced more than 3,400 pounds of sugar to the acre. Regarding Pioneer as a check, the leading varieties gave relative yields of sugar to the acre as follows:

1. Dippe W. S ........... 135
2. Extreme Pioneer (R. and G.) ................. 126
3. Wohanka (Czecho-Slovakian) .......... 123
4. Schreiber S. B ......... 121
5. Dippe E .............. 121
6. Pioneer R. and G ...... 100

IOWA (AMERICAN BEET SUGAR COMPANY)

W. H. Baird, superintendent of the American Beet Sugar Company, conducted a test of 30 varieties on the farm of the factory at Mason City, Iowa. The plats in these tests were 4 rows wide, 500 feet long, and were replicated twice. Pioneer (R. and G.) was grown every fourth plat as a check. The beets in this test were non-irrigated. The yield data are shown in Table 3.

In this test the acre yields of sugar varied from 3,200 to 4,600 pounds. Since there were checks every fourth plat, the mean of each pair of checks was regarded as 100 and the relative yields of the

[3]This variety was bred and selected by A. W. Skuderna, American Beet Sugar Company, Rocky Ford, Colorado.

intervening varieties calculated on that basis. There were no Russian varieties in this test. The relative yields of the leading 10 varieties were as follows:

1. Old Type (R. and G.) . 110.5
2. Strube E . . . . . . . . . . . . 107.2
3. Delitzscher S . . . . . . . . 106.8
4. Dippe E . . . . . . . . . . . . . 105.2
5. Extreme Pioneer (R. and G.) . . . . . . . 105.1
6. Mauzberg Z . . . . . . . . . 105.0
7. New Type (R. and G.) 104.6
8. Original (R. and G.) . . 104.5
9. Mauzberg E . . . . . . . . 104.4
10. F. Heine . . . . . . . . . . . 104.2
11. Check—Pioneer (R. and G.) . . . . . . . 100.0

## NORTH DAKOTA (STATE EXPERIMENT STATION)

The North Dakota Experiment Station conducted a test of 12 sugar beet varieties under the supervision of Robert Montgomery of

TABLE 3.—*Acre yield of roots, percentage of sugar, purity, and acre yield of sugar of 30 sugar beet varieties grown in 1928 at Mason City, Iowa.*

| Variety | Acre yield of roots in tons | Sugar content % | Purity % | Acre yield of sugar in pounds |
|---|---|---|---|---|
| Pioneer (R. and G.) (check) | 13.61 | 14.0 | 77.3 | 3,810 |
| New Type | 13.53 | 13.6 | 75.3 | 3,679 |
| Extreme Pioneer (R. and G.) | 13.29 | 13.9 | 78.9 | 3,695 |
| Original (R. and G.) | 13.17 | 13.8 | 78.4 | 3,674 |
| Pioneer (check) | 12.31 | 13.1 | 78.6 | 3,225 |
| Old Type (R. and G.) | 14.99 | 13.5 | 79.3 | 4,022 |
| Strube (s) | 12.68 | 13.1 | 80.2 | 3,323 |
| Janascz | 11.72 | 14.6 | 80.6 | 3,423 |
| Pioneer (check) | 14.91 | 13.6 | 79.6 | 4,055 |
| Strube E | 16.43 | 12.8 | 78.2 | 4,207 |
| Dippe W. I | 15.32 | 13.0 | 76.0 | 3,983 |
| Dippe E | 15.41 | 13.4 | 77.2 | 4,129 |
| Pioneer (check) | 13.65 | 13.9 | 80.0 | 3,794 |
| Braune | 14.81 | 13.1 | 77.9 | 3,881 |
| F. Heine | 15.01 | 13.3 | 77.0 | 3,993 |
| Knoche | 15.43 | 12.5 | 72.7 | 3,856 |
| Pioneer (check) | 13.82 | 14.0 | 77.9 | 3,870 |
| Wohanka | 13.85 | 14.2 | 75.9 | 3,933 |
| Zapotil | 14.25 | 13.7 | 75.8 | 3,903 |
| Dobrovice | 14.25 | 14.0 | 78.5 | 3,989 |
| Pioneer (check) | 13.55 | 14.1 | 79.7 | 3,820 |
| Mette | 12.36 | 14.1 | 75.8 | 3,484 |
| Delitzscher S | 14.94 | 14.4 | 79.8 | 4,302 |
| Delitzscher E | 13.35 | 13.9 | 80.3 | 3,711 |
| Pioneer (check) | 14.72 | 14.4 | 80.2 | 4,238 |
| Schreiber S. S | 14.44 | 14.1 | 83.7 | 4,073 |
| Schreiber S. K. W | 15.49 | 12.9 | 81.0 | 3,996 |
| Flat Foliage | 13.95 | 14.2 | 80.0 | 3,961 |
| Bergman | 14.86 | 13.7 | 79.9 | 4,092 |
| Pioneer (check) | 15.03 | 14.4 | 81.6 | 4,328 |
| Mauzberg E | 16.22 | 13.8 | 77.0 | 4,477 |
| Mauzberg Z | 16.20 | 13.9 | 79.3 | 4,504 |
| Netherlands, Elik | 16.41 | 13.5 | 78.7 | 4,430 |
| Pioneer (check) | 14.35 | 14.8 | 82.4 | 4,248 |
| Leaf Spot Res. (Iowa) | 14.27 | 13.4 | 78.9 | 3,823 |
| Iowa Flat Foliage | 14.72 | 13.8 | 79.6 | 4,061 |
| Minn. Flat Foliage | 15.42 | 14.6 | 80.8 | 4,501 |
| Deutsch | 14.73 | 14.4 | 81.1 | 4,241 |
| Pioneer (check) | 15.77 | 14.6 | 80.5 | 4,604 |

the Agronomy Department. The plats were three rows wide, 33 feet long, and were replicated three times. They were not irrigated. The summary data for this test are reported in Table 4.

TABLE 4.—*The acre yield of roots, percentage of sugar, and acre yield of sugar of 12 varieties of sugar beets grown in 1928 at Fargo. N. Dak.*

| Variety | Acre yield of roots in tons | Sugar content % | Acre yield of sugar in pounds |
|---|---|---|---|
| Pioneer (check) (R. and G.) | 15.99 | 18.1 | 5,789 |
| Old Type (R. and G.) | 15.54 | 17.4 | 5,407 |
| Dippe W. I | 17.11 | 17.6 | 6,023 |
| Dobrovice | 17.07 | 17.3 | 5,907 |
| Schreiber's Elite | 15.65 | 17.7 | 5,539 |
| Strube | 16.05 | 16.9 | 5,425 |
| Uladovka | 14.86 | 17.7 | 5,262 |
| Bielotzerkov | 15.13 | 17.7 | 5,356 |
| Vierchniatchka | 16.47 | 18.1 | 5,964 |
| Ramon | 17.65 | 17.4 | 6,141 |
| Kalnik | 14.73 | 18.8 | 5,538 |
| California | 12.91 | 17.5 | 4,520 |

Five of the 12 varieties yielded more than 5,700 pounds of sugar to the acre. Pioneer was the check variety in this test. The high-yielding varieties produced sugar in the following order and in the relative amount shown when based on Pioneer as 100:

1. Ramon (Russian) ...... 106
2. Dippe W. I .......... 104
3. Vierchniatchka (Russian) 103
4. Dobrovice ............. 102
5. Pioneer (R. and G.) .... 100

## SOUTH DAKOTA (U. S. DEPT. OF AGRICULTURE)

Beyer Aune, superintendent of the Experimental Farm of Western Irrigation Agriculture at Newell, S. Dak., grew 11 sugar beet varieties in an irrigated test replicated four times. A summary of the data for his entire test is given in Table 5.

TABLE 5.—*Acre yield of roots, percentage of sugar, purity, and acre yield of sugar of 11 sugar beet varieties grown in 1928 at Newell, S. Dak.*

| Variety | Acre yield of roots in tons | Sugar content % | Purity % | Acre yield of sugar in pounds |
|---|---|---|---|---|
| Schreiber | 20.90 | 16.0 | 85.1 | 5,691 |
| Wohanka | 18.34 | 16.1 | 84.2 | 4,972 |
| Dippe W. I | 19.92 | 17.3 | 86.7 | 5,975 |
| Pioneer (R. and G.) | 22.22 | 16.9 | 86.4 | 6,489 |
| Ramon | 21.01 | 18.2 | 86.4 | 6,608 |
| Ilyintzi | 20.59 | 16.9 | 81.9 | 5,699 |
| Bielotzerkov | 20.04 | 18.7 | 87.1 | 6,528 |
| Ivanovka | 20.47 | 18.5 | 87.6 | 6,635 |
| Vierchniatchka | 18.53 | 19.2 | 88.4 | 6,291 |
| Yaltushkov | 19.37 | 17.6 | 84.9 | 5,788 |
| Kleinwanzlebner | 18.95 | 17.6 | 86.9 | 5,796 |

In this test 6 of the 11 varieties yielded more than 5,900 pounds of sugar to the acre. The soil is unusually uniform, and all varieties appeared equal in the field, with a magnificent growth. Regarding Pioneer as a check, the five leading varieties produced sugar and in the following order in the relative amounts shown:

| | | | |
|---|---|---|---|
| 1. Ivanovka (Russian).... | 102 | 5. Vierchniatchka (Russian)........... | 97 |
| 2. Ramon (Russian)...... | 102 | 6. Dippe W. I........... | 92 |
| 3. Vielotzerkov (Russian).. | 101 | | |
| 4. Pioneer (R. and G.).... | 100 | | |

SOUTH DAKOTA (UTAH-IDAHO SUGAR COMPANY)

On the factory farm of the Black Hills Sugar Plant (Utah-Idaho Sugar Company) at Bellefourche, S. Dak., D. B. Pratt and J. F. Steck grew 14 varieties and a series of key-number strains. The plats were four rows wide and were replicated four times. The data from this test, which was irrigated, are summarized in Table 6.

TABLE 6.—*Acre yield of roots, percentage of sugar, purity, and acre yield of 14 varieties of sugar beets grown in 1928 at Bellefourche, S. Dak.*

| Variety | Acre yield of roots in tons | Sugar content % | Purity % | Acre yield of sugar in pounds |
|---|---|---|---|---|
| Schreiber........................... | 16.03 | 16.5 | 88.9 | 5,289 |
| Dippe W. I.......................... | 16.16 | 16.4 | 87.4 | 5,300 |
| Ramon (E)........................... | 16.84 | 16.3 | 87.7 | 5,490 |
| Vierchniathcka (N).................. | 14.53 | 17.5 | 89.8 | 5,085 |
| Uladovka (E)........................ | 16.61 | 17.0 | 88.8 | 5,514 |
| Kalnik (Z).......................... | 13.61 | 17.7 | 89.6 | 4,818 |
| Bielotzerkov (E).................... | 15.06 | 16.8 | 88.3 | 5,060 |
| Pioneer............................. | 16.73 | 16.9 | 89.1 | 5,655 |
| Wohanka............................. | 15.19 | 17.4 | 88.6 | 5,286 |
| Knoche E............................ | 14.86 | 16.1 | 88.8 | 4,785 |
| Braune Elite........................ | 15.95 | 17.1 | 89.5 | 5,455 |
| R. and G............................ | 16.06 | 17.2 | 89.2 | 5,525 |
| Strube.............................. | 14.45 | 17.2 | 89.1 | 4,971 |
| B. and S............................ | 13.68 | 18.1 | 90.0 | 4,952 |

Six of these 14 varieties produced 5,300 pounds or more of sugar to the acre. Regarding Pioneer as the check, the yielding order and the relative amounts of sugar to the acre follow:

| | | | |
|---|---|---|---|
| 1. Pioneer (R. and G.).... | 100 | 4. Ramon (Russian)....... | 97 |
| 2. R. and G. Seed........ | 98 | 5. Braune Elite.......... | 96 |
| 3. Uladovka (Russian).... | 98 | 6. Dippe W. I........... | 94 |

KANSAS (STATE EXPERIMENT STATION)

On the substation at Garden City, Kan., F. A. Wagner grew five varieties of sugar beets each replicated four times in irrigated plats four rows wide and 56 feet long. The data summarized in this test are given in Table 7.

TABLE 7.—*Acre yield of roots, percentage of sugar, purity, and acre yield of sugar of five sugar beet varieties grown in 1928 at Garden City, Kan.*

| Variety | Acre yield of roots in tons | Sugar content % | Purity % | Acre yield of sugar in pounds |
|---|---|---|---|---|
| Uladovka | 13.77 | 16.4 | 88.8 | 4,516 |
| Niemertche | 12.30 | 16.4 | 87.8 | 4,034 |
| Bielotzerkov | 14.70 | 16.1 | 87.0 | 4,733 |
| Pioneer (R. and G.) | 14.79 | 15.9 | 87.2 | 4,703 |
| Local Check | 13.98 | 14.9 | 86.4 | 4,166 |

The relative production of sugar to the acre for these five varieties with Pioneer as 100 was as follows:

1. Bielotzerkov (Russian).. 101
2. Pioneer (R. and G.).... 100
3. Uladovka (Russian).... 96
4. Locally distributed seed. 89
5. Niemertche (Russian)... 86

## WYOMING (STATE EXPERIMENT STATION)

Under the supervision of W. L. Quayle, director of the substations of the Wyoming Experiment Station, a comparative test of sugar beet varieties was grown on the substation at Worland, Wyo. The varieties were seeded in duplicate, one-tenth acre plats on a medium to heavy clay loam, rather spotted soil. The data are summarized in Table 8.

TABLE 8.—*Acre yield of roots, percentage of sugar, and acre yield of sugar of six varieties of sugar beets grown in 1928 at Worland, Wyo.*

| Variety | Acre yield of roots in tons | Sugar content % | Acre yield of sugar in pounds |
|---|---|---|---|
| Ivanovka | 12.74 | 17.20 | 4,383 |
| Vierchniatchka | 15.47 | 17.50 | 5,415 |
| Uladovka | 16.35 | 17.45 | 5,704 |
| Pioneer (R. and G.) | 13.01 | 17.90 | 4,654 |
| Braune | 11.61 | 16.30 | 3,785 |
| Buszczynski | 22.53 | 17.25 | 7,775 |

In this test were three Russian varieties, Pioneer, Braune Elite, and Buszcynski. The relative sugar yields in terms of Pioneer as 100 were as follows:

1. Buszczynski (Czecho-Slovakian).......... 167
2. Uladovka (Russian).... 123
3. Vierchniatchka (Russian) 116
4. Pioneer (R. and G.).... 100
5. Ivanovka (Russian).... 94
6. Braune Elite.......... 81

## COLORADO (AMERICAN BEET-SUGAR COMPANY)

A. W. Skuderna, agriculturist for the American Beet-Sugar Company, conducted a thorough-going variety test involving many varieties of sugar beets. He has supplied the part of the data given in Table 9 with the explanation that there were six replications and that the test was made under irrigation.

TABLE 9.—*Acre yield of roots, percentage of sugar, and acre yield of sugar of six sugar beet varieties grown in 1928 at Rocky Ford, Colo.*

| Variety | Acre yield of beets in pounds | Sugar content % | Acre yield of sugar in pounds |
|---|---|---|---|
| Check (Pioneer R. and G.) | 31,200 | 14.73 | 4,596 |
| Ivanovka | 29,304 | 15.51 | 4,545 |
| Uladovka | 30,201 | 14.93 | 4,509 |
| Ramon | 32,471 | 13.08 | 4,247 |
| Niemertche | 28,412 | 14.87 | 4,225 |
| Vierchniatchka | 26,387 | 14.80 | 3,905 |

With Pioneer as 100, the relative yields were as follows:

1. Pioneer (R. and G.) .... 100
2. Ivanovka (Russian) .... 99
3. Uladovka (Russian) .... 98
4. Ramon (Russian) ...... 92
5. Niemertche (Russian)... 91
6. Vierchniatchka (Russian) 85

COLORADO (U. S. DEPT. OF AGRICULTURE)

W. W. Tracy, Jr., of the U. S. Dept. of Agriculture Sugar Investigations, grew single irrigated plats of beets of about one-fifth acre. At harvest 40 beets were taken from each of eight different places for each variety. "The beets were pulled at regular intervals everywhere over the field," but there was "great variation in sugar and tonnage figures . . . in every variety." The importance of several replications and the harvesting of entire plats is here brought out very well. The summary data appear in Table 10.

TABLE 10.—*Acre yield of roots, percentage of sugar, and acre yield of sugar of six varieties of sugar beets grown in 1928 at Fort Collins, Colo.*

| Variety | Acre yield of roots in tons | Sugar content % | Acre yield of sugar in pounds |
|---|---|---|---|
| Ivanovka | 14.50 | 17.13 | 4,968 |
| Old Type (R. and G.) | 15.22 | 16.31 | 4,965 |
| Vierchniatchka | 13.94 | 17.30 | 4,823 |
| Ramon | 13.88 | 16.89 | 4,689 |
| Uladovka | 13.97 | 16.14 | 4,510 |
| Kalnik | 12.50 | 17.18 | 4,295 |

In this test were five Russian varieties with Old Type for a check. Taking this variety as 100, the relative yields were as follows:

1. Ivanovka (Russian)... 100.1
2. Old Type (R. and G.). 100
3. Vierchniatchka (Russian).......... 97
4. Ramon (Russian)...... 94
5. Uladovka (Russian)..... 91
6. Kalnik (Russian)...... 87

IDAHO (AMALGAMATED SUGAR COMPANY)

On the farm of the Utah-Idaho Sugar Company at Twin Falls, Idaho, was a large series of sugar-beet trials involving tests of various fertilizers, varieties, and cultural methods. There was a similar test

on the factory farm at Burley, Idaho. Data from a part of the varietal trials have been made available by R. H. Cottrell, general chemist of the Amalgamated Sugar Company. The plats at Twin Falls, which were irrigated, were four rows wide, 300 feet long, and

TABLE 11.—*Acre yield, percentage of sugar, purity, and acre yield of five Russian sugar beet varieties grown between check plats of R. and G. Old Type in 1928 at Twin Falls, Idaho.*

| Plat No. | Variety | Acre yield of roots in tons | Sugar content % | Purity % | Acre yield of sugar in pounds |
|---|---|---|---|---|---|
| 15 | Old Type (R. and G.) (check) | 7.2 | 19.5 | 90.5 | 2,808 |
| 16 | Ivanovka | 7.7 | 18.7 | 88.9 | 2,880 |
| 17 | Old Type (check) | 6.8 | 18.9 | 88.9 | 2,570 |
| 38 | Old Type (check) | 8.0 | 18.5 | 89.6 | 2,960 |
| 39 | Vierchniatchka | 8.0 | 19.2 | 91.0 | 3,072 |
| 40 | Old Type (check) | 7.6 | 18.5 | 88.8 | 2,812 |
| 41 | Uladovka | 9.9 | 18.0 | 87.7 | 3,564 |
| 42 | Old Type (check) | 8.1 | 17.1 | 86.7 | 2,770 |
| 61 | Old Type (check) | 6.1 | 18.8 | 89.3 | 2,294 |
| 62 | Yaltushkov | 8.0 | 18.3 | 89.0 | 2,928 |
| 63 | Old Type (check) | 8.1 | 18.2 | 89.7 | 2,948 |
| 64 | Bielotzerkov | 9.8 | 18.5 | 88.6 | 3,626 |
| 65 | Old Type (check) | 7.3 | 17.3 | 87.2 | 2,526 |

TABLE 12.—*Acre yield of roots, percentage of sugar, purity, and acre yield of sugar, and relative yield of sugar of 9 varieties and 13 of Tracy's selections of sugar beets grown in 1928 at Burley, Idaho.*

| Variety or selection | Acre yield of roots in tons | Sugar content % | Purity % | Acre yield of sugar in pounds |
|---|---|---|---|---|
| C. V. Pink | 13.81 | 16.4 | 86.8 | 4,530 |
| C. V. Flat | 13.23 | 16.2 | 85.0 | 4,280 |
| Ida High | 13.58 | 17.6 | 88.7 | 4,780 |
| Uladovka | 19.07 | 17.0 | 87.4 | 6,484 |
| Bielotzerkov | 16.90 | 17.3 | 90.0 | 5,814 |
| Vierchniatchka | 16.85 | 18.6 | 89.2 | 6,268 |
| Yaltushkov | 14.48 | 17.6 | 89.9 | 5,096 |
| Ivanovka | 18.12 | 17.6 | 88.7 | 6,378 |
| Old Type (R. and G.) | 16.09 | 17.4 | 86.7 | 5,600 |
| 357-24-1 | 18.81 | 16.4 | 88.8 | 6,170 |
| 655-24-2 | 18.03 | 17.0 | 88.0 | 6,130 |
| Old Type (R. and G.) | 18.18 | 18.4 | 89.7 | 6,690* |
| 2209-23-9 | 18.48 | 17.4 | 88.1 | 6,430 |
| 2250-24-10 | 14.37 | 17.0 | 87.6 | 4,886 |
| 2934-23-12 | 21.32 | 16.0 | 88.7 | 6,822 |
| 4088-24-12 | 20.48 | 18.0 | 89.0 | 7,372 |
| 4149-24-16 | 19.66 | 17.8 | 88.6 | 6,998 |
| 5024-23-17 | 18.84 | 17.0 | 89.6 | 6,406 |
| 2051-24-28 | 21.33 | 17.4 | 87.8 | 7,422 |
| 2533-24-27 | 13.66 | 17.8 | 86.4 | 4,862 |
| 2437-24-29 | 20.48 | 17.4 | 86.8 | 7,128 |
| 10163-26-34 | 20.47 | 17.8 | 89.7 | 7,288 |
| 5934-23-19 | 20.70 | 16.2 | 84.2 | 6,704 |
| Old Type (R. and G.) | 16.37 | 18.6 | 88.3 | 6,090* |

*Average of two checks, 6,390 pounds.

were replicated twice. The Burley plats were also irrigated and were 400 feet long. In Tables 11 and 12 are summaries of the available data from the tests. The beets at Twin Falls were badly injured by the sugar beet leafhopper (*Euttetix tenellus*) as also were those at Burley.

At Twin Falls, R. and G. Old Type used as a check was grown on both sides of each variety. Relative yields are calculated in terms of the average of the two checks. When this is done the following comparative yields of sugar to the acre were obtained:

1. Bielotzerkov (Russian).. 132
2. Uladovka (Russian).... 128
3. Yaltushkov (Russian)... 112
4. Ivanovka (Russian).... 107
5. Vierchniatchka (Russian) 106
6. Old Type (R. and G.)... 100

At Burley, the test was in two parts, each with separate checks. In the first series were three mass-selected strains of the Amalgamated Sugar Company, five Russian varieties, and the check. In the second series were 13 of Tracy's selection, with the check occurring twice. When the checks for each series were regarded as 100, the comparative sugar yields were:

1. Tracy 2051–24–28...... 116
2. Uladovka (Russian).... 116
3. Tracy 4088–24–15...... 115
4. Ivanovka (Russian).... 114
5. Tracy 10163–26–34..... 114
6. Vierchniatchka (Russian) 112
7. Tracy 2437–24–29...... 112
8. Tracy 4149–24–16...... 110
9. Old Type (R. and G.)... 100

## UTAH (STATE EXPERIMENT STATION)

In Utah, under the writer's supervision, were three varietal trials—one on the Central Experimental Farm at North Logan, one on the substation farm at Price, and the third on the farm of Silvin Peterson at Benson (8 miles from Logan). The last-named test was cooperative on the one hand with the Amalgamated Sugar Company which rented the land and provided for its care by Mr. Peterson, and on the other hand with the Utah Experiment Station. The writer personally planned the test, aided in sowing it, and supervised its care and harvesting.

The plats of the Logan test were four rows wide, 100 feet long, and were replicated four times. The substation tests at Price were the same size and replicated three times. The Benson tests were four rows wide, 200 feet long, and were replicated twice, except that three varieties were seeded a third time in order to fill the space provided. All tests were irrigated. Summaries of the data from these three tests are given in Table 13.

TABLE 13.—*Acre yield of roots, percentage of sugar, purity, and acre yield of sugar for sugar beet varieties grown in Utah, 1928.*

| Order of pounds of sugar per acre | Variety | Acre yield of roots in tons | Purity % | Acre yield of sugar in pounds | Sugar content % |
|---|---|---|---|---|---|
| | **Logan*** | | | | |
| 1 | Uladovka | 21.11 | 84.85 | 6,599 | 15.63 |
| 2 | Dippe W. I | 19.12 | 86.90 | 6,424 | 16.80 |
| 3 | Danish (1925) | 20.77 | 85.00 | 6,389 | 15.38 |
| 4 | Tetkino | 18.92 | 85.45 | 6,206 | 16.40 |
| 5 | Ramon | 20.16 | 84.30 | 6,149 | 15.25 |
| 6 | Pioneer (checks) (R. and G.) | 19.98 | 85.61 | 6,137 | 15.92 |
| 7 | Niemertche | 18.25 | 86.45 | 5,997 | 16.43 |
| 8 | Original | 18.48 | 85.17 | 5,980 | 16.18 |
| 9 | Bielotzerkov | 17.91 | 86.35 | 5,975 | 16.68 |
| 10 | Kalnik | 17.76 | 84.92 | 5,868 | 16.52 |
| 11 | Braune Elite | 19.38 | 84.12 | 5,861 | 15.12 |
| 12 | Ivanovka | 17.76 | 85.42 | 5,836 | 16.43 |
| 13 | Knoche | 19.05 | 84.50 | 5,791 | 15.20 |
| 14 | Wohanka | 18.74 | 85.07 | 5,689 | 15.18 |
| 15 | Vierchniatchka | 17.73 | 86.05 | 5,636 | 15.90 |
| 16 | Montfort | 16.98 | 86.17 | 5,624 | 16.56 |
| 17 | Yaltushkov | 16.03 | 85.17 | 5,258 | 16.40 |
| 18 | Ilyintzi | 16.09 | 85.72 | 5,175 | 16.08 |
| | **Price** | | | | |
| 1 | Bielotzerkov | 19.41 | | 6,559 | 16.9 |
| 2 | Uladovka | 21.14 | | 6,510 | 15.4 |
| 3 | Ivanovka | 18.51 | | 6,495 | 17.5 |
| 4 | Vierchniatchka | 20.71 | | 6,462 | 15.6 |
| 5 | Knoche | 20.91 | | 6,105 | 14.6 |
| 6 | Schreiber | 17.94 | | 6,098 | 17.0 |
| 7 | Dippe | 18.49 | | 5,917 | 16.0 |
| 8 | Wohanka | 16.70 | | 5,676 | 17.0 |
| 9† | Pioneer (check) (R. and G.) | 16.79 | | 5,584 | 16.8 |
| 10 | Yaltushkov | 17.78 | | 5,545 | 15.6 |
| 11 | Ilyintzi | 18.96 | | 5,381 | 14.2 |
| 12 | Dippe | 16.50 | | 5,379 | 16.3 |
| 13 | Niemertche | 19.89 | | 5,372 | 13.5 |
| 14 | Synowie (Factory Check) | 17.46 | | 4,748 | 13.6 |
| | **Benson** | | | | |
| 1 | Pioneer (R. and G.) | 18.22 | 85.72 | 5,958 | 16.33 |
| 2 | Bielotzerkov | 19.14 | 84.55 | 5,865 | 15.32 |
| 3 | Uladovka | 17.27 | 86.05 | 5,795 | 16.78 |
| 4 | Ivanovka | 17.04 | 86.12 | 5,586 | 16.08 |
| 5 | Dippe W. I | 16.89 | 85.32 | 5,388 | 15.95 |
| 6 | Niemertche | 16.41 | 85.40 | 5,309 | 16.18 |
| 7 | Vierchniatchka | 16.84 | 84.82 | 5,282 | 15.68 |
| 8 | Braune | 16.30 | 85.27 | 5,209 | 15.98 |
| 9 | Wohanka | 15.42 | 84.80 | 5,019 | 16.28 |
| 10 | Knoche | 16.55 | 83.85 | 5,006 | 15.12 |
| 11 | Factory Seed | 15.06 | 86.75 | 5,137 | 17.05 |

*Each variety replicated four times with checks every sixth plat. The plats consisted of four rows 100 feet long; at harvest the two middle rows were used for data, one outer row on each side being regarded as a border.

†Average of nine plats of check varieties. The check varieties were grown every sixth plat, that is, there were four test varieties, followed by the two checks, and then four other test varieties and two checks, etc., to the end.

Of the 18 varieties tested at Logan, 6 yielded more than 6,000 pounds of sugar to the acre. With Pioneer as 100, the comparative yields were as follows:

1. Uladovka (Russian).... 108
2. Dippe W. I........... 105
3. Danish (1925 seed)..... 104
4. Tetkino (Russian)...... 101
5. Ramon (Russian)....... 100
6. Pioneer (R. and G.).... 100

In the Price trials, 6 varieties out of 14 yielded more than 6,000 pounds of sugar to the acre. With Pioneer as 100, the relative yields were as follows:

1. Bielotzerkov (Russian).. 117
2. Uladovka (Russian).... 117
3. Ivanovka (Russian).... 116
4. Vierchniatchka (Russian) 116
5. Knoche "E"........... 109
6. Dippe W. I........... 109
7. Pioneer (R. and G.) ... 100

In the Benson test were five Russian and six other varieties. With Pioneer as 100, the five highest yielding varieties were as follows:

1. Pioneer (R. and G.).... 100
2. Bielotzerkov (Russian).. 98
3. Uladovka (Russian).... 97
4. Ivanovka (Russian).... 94
5. Dippe W. I........... 90

CALIFORNIA (STATE EXPERIMENT STATION)

W. W. Robbins, botanist at University Farm, Davis, Calif., tested the yield of six sugar beet varieties in irrigated tests replicated four times. Each plat was 16 rows wide and 50 feet long. A summary of the data obtained from this test is given in Table 14.

TABLE 14.—*Acre yield of roots, percentage of sugar, and acre yield of sugar of six sugar beet varieties grown in 1928 at Davis, Calif.*

| Variety | Acre yield of roots in tons | Sugar content % | Acre yield of sugar in pounds |
|---|---|---|---|
| Bielotzerkov | 29.5 | 14.9 | 8,857 |
| Uladovka | 28.0 | 15.7 | 8,930 |
| Uladovka | 28.5 | 15.5 | 8,930 |
| Ivanovka (Y) | 27.0 | 16.5 | 8,930 |
| Ivanovka (S) | 27.0 | 16.1 | 8,785 |
| Old Type (R. and G.) | 30.5 | 15.5 | 9,583 |

In the Califronia tests were five Russian varieties with Old Type used as a check. Two lots of Uladovka were obtained and both were seeded. The comparative sugar yields are indicated below with Old Type as 100.

1. Old Type (R. and G.)... 100
2. Uladovka (Russian).... 93
3. Uladovka (Russian).... 93
4. Ivanovka (Y) (Russian). 93
5. Bielotzerkov (Russian).. 93
6. Ivanovka (Sugar Type). 92

OREGON (U. S. DEPT. OF AGRICULTURE)

In an experiment conducted at the Oregon Experiment Station at Corvallis, H. A. Schoth of the U. S. Department of Agriculture grew six varieties of sugar beets without irrigation. The plats were three rows wide, 103 feet long, and were replicated twice. The yield data are given in Table 15.

TABLE 15.—*The acre yield of roots, percentage of sugar, and acre yield of sugar of six sugar beet varieties grown in 1928 at Corvallis, Oregon.*

| Variety | Acre yield of roots in tons | Sugar content % | Acre yield of sugar in pounds |
|---|---|---|---|
| Ramon | 11.34 | 17.2 | 3,901 |
| Niemertche | 11.58 | 17.9 | 4,146 |
| Ilyintzi | 10.86 | 17.3 | 3,758 |
| Kalnik | 9.72 | 18.4 | 3,577 |
| Yaltushkov | 9.48 | 17.7 | 3,356 |
| Check (U. S. D. A.) | 9.78 | 16.5 | 3,227 |

Computed on the basis of 100 for the unnamed check, the relative yields were as follows:

1. Niemertche (Russian)... 128
2. Ramon (Russian)...... 121
3. Ilyintzi (Russian)...... 116
4. Kalnik (Russian)....... 111
5. Yaltushkov (Russian)... 104
6. Check (U. S. Dept. Agri. Seed)............... 100

## CANADA (CHARLOTTETOWN, PRINCE EDWARD ISLAND, EXPERIMENTAL FARM)

On the experimental farm at Charlottetown, Prince Edward Island, were grown 10 sugar beet varieties without irrigation. The plats were replicated three times, but the size of the plats is not stated. It seems that these were grown primarily for stock feed; but since the sugar content and purity are given, the data for sugar yield can also be calculated as shown in Table 16. Several other tests were grown in Canada, but since they seem not to have been replicated, they are not included here.

TABLE 16.—*Acre yield of roots, percentage of sugar, purity, and acre yield of sugar of 10 sugar beet varieties grown in 1928 at Charlottetown, P. E. I., Canada.*

| Variety | Acre yield of roots in tons | Sugar content % | Purity % | Acre yield of sugar in pounds |
|---|---|---|---|---|
| Ramon | 14.96 | 17.95 | 86.30 | 5,369 |
| Dippe | 14.08 | 18.65 | 88.12 | 5,253 |
| Kalnik | 13.65 | 18.76 | 86.86 | 5,121 |
| Niemertche | 13.50 | 18.62 | 87.98 | 5,029 |
| Uladovka | 13.50 | 18.07 | 86.18 | 4,880 |
| Fredericksen | 12.63 | 18.55 | 87.06 | 4,687 |
| Vierchniatchka | 12.49 | 18.54 | 87.32 | 4,631 |
| Buszczynski | 11.91 | 19.28 | 88.41 | 4 591 |
| Bielotzerkov | 12.20 | 18.67 | 86.62 | 4,555 |
| Kalnik | 10.56 | 18.79 | 87.16 | 3,983 |

When the variety Fredericksen was taken as 100, the varieties in order of relative acre yields of sugar were as follows:

1. Ramon (Russian)...... 114
2. Dippe................. 112
3. Kalnik (Russian)....... 109
4. Niemertche (Russian)... 107
5. Uladovka (Russian).... 104
6. Fredericksen......... 100
7. Vierchnitchka (Russian) 99
8. Buszczynski.......... 98
9. Bielotzerkov (Russian). 97
10. Kalnik (Russian)...... 85

## SUMMARY

In order to obtain accurate composite comparisons between various sugar beet varieties, it would be necessary to have at least an appreciable part of the varieties represented in all tests. Unfortunately, there was in 1928 a wide variation both in the varieties tested and in the check used.

The tests fall into three groups in which it seems wise to summarize the yield data, *viz.*, (1) non-irrigated tests including more than 10 varieties, (2) irrigated tests including more than 10 varieties, and (3) irrigated tests containing less than 10 varieties. The varieties are ranked in order of acre yield of sugar and are numbered consecutively.

There were five tests in non-irrigated regions, each of which included 12 or more varieties. The three Minnesota tests each included 19 varieties; the North Dakota test, 12; and the Michigan test, 51. The order of yield data is summarized in Table 17.

TABLE 17.—*Varieties of non-irrigated sugar beets listed according to the place tested and according to the rank in yield of sugar per acre of the various varieties grown at the place designated.**

| | Univ. Farm, Minn. | Waseca, Minn. | Crookston, Minn. | Fargo, N. Dak. | Saginaw, Mich. | Mason City, Iowa |
|---|---|---|---|---|---|---|
| Number varieties grown | 19 | 19 | 19 | 12 | 51 | 30 |
| Bielotzerkov (Russian) | 17 | 8 | 11 | 10 | 3 | — |
| Braune's Elite | 19 | 2 | 7 | — | 11 | 17 |
| Delitzscher | 2 | 9 | 9 | — | 24 | 3 |
| Dippe's W. I. | 1 | 11 | 1 | 2 | 49 | 15 |
| Ivanovka (Russian) | 15 | 3 | 14 | — | 28 | — |
| Janascz (Polish) | 8 | 7 | 8 | — | 39 | 23 |
| Knoche "E" | — | — | — | — | 26 | 18 |
| Old Type (R. and G.) | 14 | 14 | 12 | — | 19 | 7 |
| Original (R. and G.) | 3 | 1 | 13 | — | 48 | 8 |
| Pioneer (R. and G.) | 7 | 18 | 18 | 5 | 35 | 19 |
| Schreiber's S. K. W. | 5 | 4 | 6 | 6 | 12 | 24 |
| Strube | 13 | 10 | 4 | 8 | 16 | 28 |
| Uladovka (Russian) | 18 | 6 | 15 | 11 | 6 | — |
| Vierchniatchka (Russian) | — | — | — | 3 | 4 | — |
| Wohanka (Czecho-Slovakian) | 9 | 13 | 3 | — | 11 | 13 |

*The higher sugar yielder at a given place is designated as 1, the next highest as 2, etc., consecutively.

Perhaps the most striking thing about this summary is the lack of agreement at the various places. Dippe W. I. ranked first at University Farm and at Crookston, Minn. It was second at Fargo, N. Dak., but eleventh in 19 varieties at Waseca, Minn., and forty-ninth in 51 varieties at Saginaw, Mich. The Russian variety Bielotzerkov, was third in Michigan, but seventeenth, eighth, eleventh, and tenth at the other places. Schreiber yielded fifth, fourth, sixth, sixth, and twelfth at the places in order from left to right in Table 17.

So far as Minnesota and North Dakota are concerned, Dippe W. I. and Schreiber performed somewhat more consistently than the others, but even these are anything but outstanding.

Of the larger irrigated tests, there were two in South Dakota with 11 and 14 varieties, respectively; one in Idaho with 22; and three in Utah with 18, 11, and 16 varieties. Table 18 gives a summary of yielding rank of the varieties in these tests.

TABLE 18.—*Varieties of irrigated sugar beets listed according to the place tested and according to the rank in yield of sugar per acre of the various varieties grown at the place designated.**

| | Newell, S. Dak. | Belle-fourche, S. Dak. | Burley, Idaho | Logan, Utah | Benson, Utah | Price, Utah |
|---|---|---|---|---|---|---|
| Number of varieties grown | 11 | 14 | 22 | 18 | 11 | 16 |
| Bielotzerkov (Russian)... | 3 | 10 | 11 | 9 | 2 | 9 |
| Braune's Elite.......... | — | 5 | — | 11 | 8 | — |
| Dippe's W. I........... | 6 | 6 | — | 2 | 5 | 12 |
| Ivanovka (Russian)..... | 1 | — | 4 | 12 | 4 | 3 |
| Knoche "E"........... | — | — | — | 13 | 10 | — |
| Pioneer (R. and G.)..... | 4 | 1 | — | 6 | 1 | 2 |
| Ramon (Russian)....... | 2 | 4 | — | 5 | — | — |
| Schreiber's............. | 8 | 7 | — | — | — | 6 |
| Uladovka (Russian)..... | — | 3 | 2 | 1 | 3 | 2 |
| Vierchniatchka (Russian) | 5 | 9 | 6 | 15 | 7 | 4 |
| Wohanka (Czecho-Slovakian)........... | 10 | 8 | — | 14 | 9 | 8 |

*The highest sugar yielder at a given place is designated as 1, the next highest as 2, etc., consecutively.

The variety yields included in Table 18 are much more consistent than those in Table 17. The Russian variety Uladovka has no number other than 1, 2, or 3 and seems to be a consistently good producer in South Dakota, Idaho, and Utah. Dippe W. I. is rather consistently near the middle of the list and Wohanka relatively near the lower end. R. and G. Pioneer was a good performer, though not so consistently good as Uladovka.

Scattered across the irrigated region were six tests which included less than 10 varieties. These were located as follows: One in Kansas with five varieties; two in Colorado with six each; and one each of six varieties in Wyoming, Idaho, and California. Unfortunately, these differed rather widely as to the varieties used. Some included "local seed" with the variety not designated; while some included a variety not grown elsewhere and which, therefore, afforded little opportunity for comparison. Two of these (Braune's Elite and Buszczynski) are reported on account of having occurred in the other tests. The rankings as to sugar yield are summarized in Table 19.

The varieties used in the Oregon test were too different to permit being included in either table. The single Canadian test was so far east and so far north that it was thought better to leave it by itself.

TABLE 19.—*Varieties of irrigated sugar beets listed according to place tested and according to the rank in yield of sugar per acre of the various varieties grown at the place designated.**

| | Garden City, Kans. | Fort Collins, Colo. | Rocky Ford, Colo. | Worland, Wyo. | Twin Falls, Idaho | Davis, Calif. |
|---|---|---|---|---|---|---|
| Number varieties grown | 5 | 6 | 6 | 6 | 6 | 6 |
| Bielotzerkov (Russian) | 1 | — | — | — | 1 | 4 |
| Braune's Elite | — | — | — | 6 | — | — |
| Buszczynski | — | — | — | 1 | — | — |
| Ivanovka (Russian) | — | 1 | 2 | 5 | 4 | 3 |
| Old Type (R. and G.) | — | 2 | — | — | 6 | 1 |
| Pioneer (R. and G.) | 2 | — | 1 | 4 | — | — |
| Ramon (Russian) | — | 4 | 4 | — | — | — |
| Uladovka (Russian) | 3 | 5 | 3 | 2 | 2 | 2 |

*The highest sugar yielder is designated as 1, the next highest 2, etc., consecutively.

There are too many omissions in Table 19 to permit any definite conclusions. However, the Russian variety Uladovka has all numbers except one in the first three places. In every case the highest yielding variety was some variety other than Uladovka, and in each case it was a different one except Bielotzerkov (Russian), which was first at two places. Uladovka was perhaps the most consistent performer.

## CONCLUSIONS

Probably the one really apparent conclusion to be derived from the 1928 tests is the difficulty of arriving at any important decision when rather dissimilar sets of varieties are grown at different places. If ten or a dozen varieties could be grown at all places as a nucleus, with ones of local interest grown in addition, some reliable idea of the performance of these ten or dozen varieties could be arrived at in three to five years. The plat technic is also too varied to produce comparative results. With each test a separate unit, the trials are too much like mere driblets for the experimental stream to flow anywhere in particular. Obviously, some agency is badly needed to bring about such an organization. It is hoped this effort may lead at least some of the way in that direction.

## NOTE

### LIME, POTASH, AND ALFALFA ON PIEDMONT SOILS

When cotton is planted after alfalfa on Piedmont soils, it is very common to notice signs of potash hunger on the cotton. This condition is called "rust" by the farmers. The explanation commonly given of this condition is that it is caused by the alfalfa removing large amounts of potash from the soil. This explanation seemed reasonable as in five years time the potash removed from an alfalfa field would amount to 1,000 pounds per acre. As the surface 7 inches of many of the Piedmont soils do not contain more than a total of 5,000 to 10,000 pounds of available and unavailable potash per acre, the removal of 1,000 pounds would seem to account for rust on cotton planted after alfalfa.

On a trip through South Carolina in the fall of 1928, a field of cotton was visited which was very heavily rusted. Questioning the owner of the land, the history of the field was found to be as follows:

Three years before the cotton crop was planted, the field had been limed with about 2 tons of limestone per acre in preparation for planting alfalfa. For some reason the alfalfa was not planted. The owner reported that rust had been bad on the cotton in this field every year since the lime was applied.

On part of the field the N. V. Potash Company had made a heavy application of potash as a demonstration. Where the potash was applied no rust was observed.

It appears from this that rust or potash hunger in cotton following alfalfa is caused by the lime which is always applied for alfalfa in this section. The old idea that lime liberates potash does not seem to be true on these soils. Either the lime locks up the potash, so that the cotton plant cannot get it, or the lime greatly increases the need of cotton for this element.—R. P. Bledsoe, *Georgia Agricultural Experiment Station, Experiment, Ga.*

# AGRONOMIC AFFAIRS

## MEETING OF CORN BELT SECTION

The annual meeting of the Corn Belt Section of the American Society of Agronomy was held at Manhattan and Hays, Kansas, on June 12, 13, and 14. One hundred and ten representatives from Indiana, Iowa, Kansas, Michigan, Missouri, Montana, Nebraska, Oklahoma, Ohio, Wisconsin, and the United States Department of Agriculture and from several commercial organizations were in attendance. The 12th and the fore-noon of the 13th were spent studying the experimental plats of the Kansas Agricultural Experiment Station at Manhattan. On the afternoon of the 13th, the party drove to the Fort Hays Branch Experiment Station and the 14th was spent examining the extensive experimental plats at that station. The party also took advantage of the opportunity to see in operation, much of the modern machinery that is now used in producing wheat in the Kansas wheat belt. The extensive forest nursery of the Fort Hays Branch Station was also visited. An invitation to meet at the Nebraska Experiment Station next year was accepted.

## NEWS ITEMS

DURING May a group of agronomists and agriculturists representing the Grain Trust Corporation of Moscow, Russia, visited the North Dakota Agricultural College. They proposed to spend a month or two on the larger farms in North Dakota to become familiar with tractor and machine farming, particularly in relation to wheat growing. This corporation proposes to operate 15,000,000 acres of land in Russia with machinery to be bought from America. The party included the following: M. E. Kovarsky, agricultural engineer and general manager of Ukrainian Grain farms; V. K. Rosental, member of the board of directors of the Grain Trust Corporation of Moscow; M. F. Mityaeff, agronomist; O. I. Palguy, agriculturist; I. T. Skorospeshkin, agronomist; K. D. Postojalkoff, agronomist; P. G. Popoff, agronomist; P. A. Schmidtt, agronomist and manager of Volga district grain farms; I. K. Andrievsky, agronomist; I. S. Kazbrekoff, agronomist; G. L. Nikolaenko, agronomist; and Interpreter Timothy A. Berseney, graduate of Columbia University.

THE FIFTH Soil and Land Valuation Short Course was held at the Iowa State College May 8 and 9. Approximately 250 were in attendance, including land appraisers and representatives of banks, insurance, mortgage, and other loan companies. The opening talk of the short course was given by Professor M. F. Miller, head of the Soils Department of the University of Missouri. Other addresses were given by Dr. W. H. Stevenson, Dr. P. E. Brown, and the staff members of the Iowa State College Soils Department. The discussion was chiefly on the subject of soil origins, characteristics, and types in relation to fertility, land valuation, and appraisals.

W. J. LEIGHTY, formerly on the Soil Survey staff at the University of Illinois, has been appointed Assistant in Soil Survey at the Iowa Agricultural Experiment Station.

H. V. Geib, who has been pursuing graduate work toward the doctor's degree in soils at the Iowa State College, has accepted a position with the Bureau of Chemistry and Soils and has been given charge of a new experiment station at Temple, Texas, where studies will be conducted on soil erosion and moisture conservation.

R. H. Walker, Assistant Chief in Soil Bacteriology, Iowa Agricultural Experiment Station, was elected chairman of the Bacteriology Section of the Iowa Academy of Science for the ensuing year at the meetings held at Fairfield, Iowa, April 26 and 27.

On April 26, the Advisory Committee on Forage and Grain Crops of the New England Section of the Society and invited representatives from the experiment stations of New York, Pennsylvania, Delaware, and Maryland, met with representatives of the Eastern States Farmers' Exchange at Springfield, Mass. Work under way at the various stations represented was presented, and problems of zoning and allocation of phases of experimental work were discussed. Some committee assignments were made with instructions to report at the fall meeting of the New England Section.

The Ames Section of the American Society of Agronomy at the Iowa State College has completed its program for the school year. Meetings have been held every other Wednesday and topics of general agricultural interest have been discussed by men especially well qualified in their field of work. Following is a list of the subjects presented during the year: Report on the National Meetings at Washington, W. H. Stevenson and P. E. Brown; The Status of Research in Europe, E. W. Lindstrom; An Analysis and Summary of Growth Processes, W. E. Loomis; Forests, Types, Uses, and Related Problems, D. S. Jeffers; Stock Hardiness in Apples, T. J. Maney; The Experiment Station Project, W. H. Stevenson; The Federal Reserve and Iowa Banking, F. L. Garlock; The Utilization of Sewage Waste, Max Levine; and The Rôle of Government in Present-Day Society, G. W. Rutherford.

Louis R. Jorgenson, Assistant Agronomist, U. S. Dept. of Agriculture, stationed at Columbus, Ohio, on corn investigations, was granted the degree of Doctor of Philosophy, Division of Agronomy and Plant Genetics, University of Minnesota, in June. His thesis problem was "Brown Midrib in Maize and its Linkage Relations."

## A CORRECTION

On page 661 of this volume of the Journal, in the article on "Eradicating Brush and Weeds from Pastures", the term sodium arsenate, used in lines 1, 13, and 14, should read sodium arsenite.

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## CHEMICAL AND MICROBIOLOGICAL PRINCIPLES UNDERLYING THE TRANSFORMATION OF ORGANIC MATTER IN STABLE MANURE IN THE SOIL[1]

SELMAN A. WAKSMAN AND ROBERT A. DIEHM[2]

Among the sources of organic matter and plant nutrients returned to the soil to replace the losses resulting from the activities of micro-organisms and the growth of higher plants, stable manures still occupy, in addition to plant residues and green manures, a very prominent place.

The rôle played by stable manure in soil processes has been variously ascribed to four distinct factors, *viz.*, (a) manure offers a readily available supply of nitrogen, phosphoric acid, and potash for the growth of higher plants; (b) it is a good source of $CO_2$ necessary for plant growth, due to the action of the micro-organisms upon the carbon complexes in the manure; (c) the organic matter of the manure serves the purpose of replenishing the supply of soil organic matter or "soil humus"; and (d) manure exerts an important influence upon the microbiological activities in soil. In many instances claims were put forth that the importance of stable manure in soil productivity is actually due to its bacterial content, the value of the manure thus being ascribed to its inoculating properties.

The processes involved in the decomposition and in the use of manure, both in the compost heap and directly in the field, are thus found to involve three distinct phenomena, namely, (a) the transformation of the organic matter in the manure in general, (b) the transformation of the nitrogen complexes in the decomposition

[1]Contribution from the Department of Soil Chemistry and Bacteriology, New Jersey Agricultural Experiment Station, New Brunswick, N. J. Received for publication February 2, 1929.

This is the third and last of a series of articles dealing with the principles underlying the utilization of natural organic materials on the farm.

[2]Microbiologist and Research Assistant, respectively.

of the manure, and (c) the rôle of the micro-organisms found in large numbers in the manure upon the microbiological population of the soil and upon soil processes. In addition to these problems, the use of stable manure in soil also involves a study of its effect, directly or through the decomposition products, upon the physical condition of the soil as well as upon making the soil a favorable medium for the growth of micro-organisms.

The transformation of nitrogen in manure, leading to its final liberation in a form available for the growth of higher plants, namely as ammonia, is closely connected with the general processes of decomposition of the organic matter in the manure. The activities of the micro-organisms in the manure are also dependent on and are closely connected with the transformation of its organic and inorganic complexes. In view of these considerations, it is sufficient to study the processes of decomposition of the organic complexes in the manure, and the rôle of the different groups of micro-organisms in these processes, to be able to throw light upon the various phases of the subject previously mentioned.

Hébert (5)[3] stated nearly 40 years ago that in his studies on the chemical composition of straw he discovered that a "highly carbonaceous substance," described by Dehérain (2) as "vasculose" and later found to be identical with the substance which is now usually known as lignin, appears in large proportion in manure. One of the benefits resulting from the addition of manure to soil was believed to be due to the restoration of this carbonaceous principle which has been exhausted by the growth of certain plants.

Hébert (6, 7) further reported the results of Müntz and Girard who investigated the manure of five sheep. Each sheep excreted daily 2.05 kg of faeces which contained 73.6% water, 0.51% nitrogen, 0.31% $P_2O_5$, and 0.87% $K_2O$. As a result of the "fermentation" of the manure, the water-soluble and fatty substances, as well as the "straw gum," modern pentosan, were found to be the first to decompose, followed by the cellulose. The "vasculose" was only partly destroyed and variously modified, but a large part of it still remained in the residual compost.

This is clearly brought out in Table 1, in which the results of Hébert's experiments are cited. Various mineral substances, containing 2.64% of nitrogen in the form of ammonium salts and 2.75% of ash, were added to the straw. The compost was then inoculated with manure and incubated, at 55°C, under aerobic and anaerobic conditions. These results, namely, the greater resistance of the

[3]Reference by number is to "Literature Cited," p. 809.

TABLE 1.—*Decomposition of straw in the presence of inorganic nutrients under aerobic and anaerobic conditions (Hébert).*

| Chemical complexes | Percentage of dry matter | | |
|---|---|---|---|
| | Straw at start | Composted straw | |
| | | Aerobic | Anaerobic |
| $NH_3$ | 2.64 | 0.40 | 1.40 |
| Organic N | 0.39 | 1.20 | 1.48 |
| Ether-soluble substances | 0.46 | 0.30 | 0.29 |
| Water-soluble substances | 1.53 | 0.26 | 0.15 |
| Cellulose | 14.12 | 6.18 | 5.98 |
| Straw gum (xylan) | 10.00 | 4.67 | 3.97 |
| Vasculose (lignin) | 14.01 | 11.75 | 8.91 |
| Ash | 6.32(3.57+2.75*) | 6.40 | 5.56 |

*The 2.75% ash was added in the form of mineral nutrients.

lignins ("vasculose") than of the celluloses and of the pentosans ("straw gum") to decomposition, even with the imperfect methods of analysis of the organic complexes in use 40 years ago, are fully confirmed in recent studies. The same is true of the transformation of the additional inorganic nitrogen in the form of ammonium salts into organic nitrogenous compounds.

According to Dehérain (3), the rôle of litter in manure consists not only in the absorbtion of the liquids excreted by the animals and in supplying a soft bed for them, but also in supplying "vasculose" (lignin), a substance which after transformation was believed to characterize the manure and to give to it its special fertilizing value. A knowledge of the chemical composition of the litter was, therefore, considered to be of great importance.

In experiments on feeding sheep, carried out by Gay and Dupont and reported by Dehérain (3), whereby all the urine and faeces were carefully collected, the following nitrogen balance was obtained:

| | | |
|---|---|---|
| Nitrogen in oats, 2.67% | 79.6 | grams |
| Nitrogen in alfalfa hay, 2.06% | 91.5 | grams |
| Nitrogen in total feed | 171.1 | grams |
| Nitrogen excreted in faeces, 2.27% | 65.4 | grams |
| Nitrogen excreted in urine | 98.0 | grams |
| Nitrogen in total manure | 163.4 | grams |
| Loss of nitrogen | 7.7 | grams |

To illustrate further the fact how well the processes involved in the composting of manure were understood by the earlier chemists and agronomists, it is sufficient to cite the conclusions of Dehérain:

Manure was found to consist of the insoluble residue of straw left after the loss of the easily decomposable carbohydrates due to "aerobic fermentation." There was a certain diminution in the "vasculose" (lignin) content due to the chemical action of alkali carbonates accompanied by a partial decomposition of the celluloses by anaerobic bacteria and a decrease of the nitrogenous substances as well as of minerals in the solid and liquid animal excreta. Dehérain states definitely that the micro-organisms actually consume the ammoniacal nitrogen of the manure for the building up of their tissues. On the other hand, they are also capable of decomposing organic matter and of liberating a part of the nitrogen in an available state. These two reactions take place under different conditions, first, the formation of microbial organic matter takes place at the expense of the inorganic nitrogen, and second, this is followed by the decomposition of the proteins and the liberation of some of the nitrogen as ammonia.

According to König and associates (10), the decomposition of stable manure involves the process of oxidation of the carbon compounds, so that 75% of the carbon disappears at the end of the first year after the application of the manure to the soil. The decomposition is more rapid during the warmer period of the year than during the colder. Pentosans are decomposed more rapidly than the total organic matter, while the lignins are decomposed more slowly. Decomposition of manure is thus found to be accompanied by a gradual enrichment in the lignins, as shown by an increase in the methoxyl content. Both the total and easily soluble nitrogen compounds in the manure diminish rapidly after its application to the soil. This was believed to be due either to denitrification or to a removal of the nitrogen to the subsoil. Only about a third of the nitrogen and of the phosphoric acid in the manure was made available to the growing crops during the first two years after the application of the manure, while 70% of the potash was made available in that period of time.

In his earlier studies on the digestion by sheep of grass hay and clover hay, harvested at different stages of growth, König (9) found that the higher the lignin and cutin content of the plant materials, the less readily were they digested. Celluloses and pentosans were found to be more readily digestible than lignins. According to a recent contribution by Rubner (12), celluloses of different origin differ markedly in their digestibility. Lignin itself was found to be digested partly in the animal organism, but to a considerably less extent than celluloses and pentosans.

These results may lead one to conclude *a priori* that the chemical composition of the manure will depend upon the chemical composition of the animal foodstuffs and upon the degree of digestibility of the various organic complexes in those foodstuffs, as well as upon the nature of the metabolic processes in the animal organism.

The results of the early French agronomists reported previously, as well as numerous other studies of more recent origin, definitely established the fact that at least a half of the nitrogen, and frequently more, of the manure is found in the urine as urea and ammonium carbonate. This part of the nitrogen nitrifies very readily as soon as the manure is added to the soil. Even the presence of straw does not reduce the rapidity of the process of nitrate formation. The nitrogen in the solid excreta does not change readily into nitrates and may take place only after the manure has been composted for a considerable period of time (8).

Barthel and Bengtsson (1) freed stable manure from the ammonia nitrogen present in it by distillation with or without a vacuum. When this manure was then added to various soils no nitrate formation took place, thus proving their previous results that only the ammoniacal (and urea) nitrogen in the manure undergoes active nitrification, but not the nitrogen present in the manure in the form of organic compounds.

According to Egorov (4), one-half to two-thirds of the nitrogen in the solid excreta of the manure is in the form of bodies of microorganisms. The presence of fungi in the process of decomposition of the manure was found to lead to smaller losses of nitrogen than in the absence of fungi. The influence of moisture and aeration upon the rapidity and nature of decomposition of several of the most important organic complexes during the process of composting of fresh horse manure at 35–37°C is best illustrated by the results of Egorov (Fig. 1).

## EXPERIMENTAL

Several experiments will be reported here which will tend to illustrate the nature of the chemical complexes in stable manure and the processes of decomposition involved in the composting of this manure.

### EXPERIMENT I

Two sheep were placed on a special diet, consisting of timothy hay and rolled oats in addition to a supply of ordinary table salt and sufficient water. The amount of feed consumed was carefully recorded and the manure was collected, weighed, and analyzed.

The sheep were kept in special pens with metal floors which allowed the urine to drain into a special receptacle, both urine and solid excreta being mixed and dried in an oven at 60°C. The sheep were fed on the special diet for two weeks before a careful record was taken of the consumption of feed and production of manure.

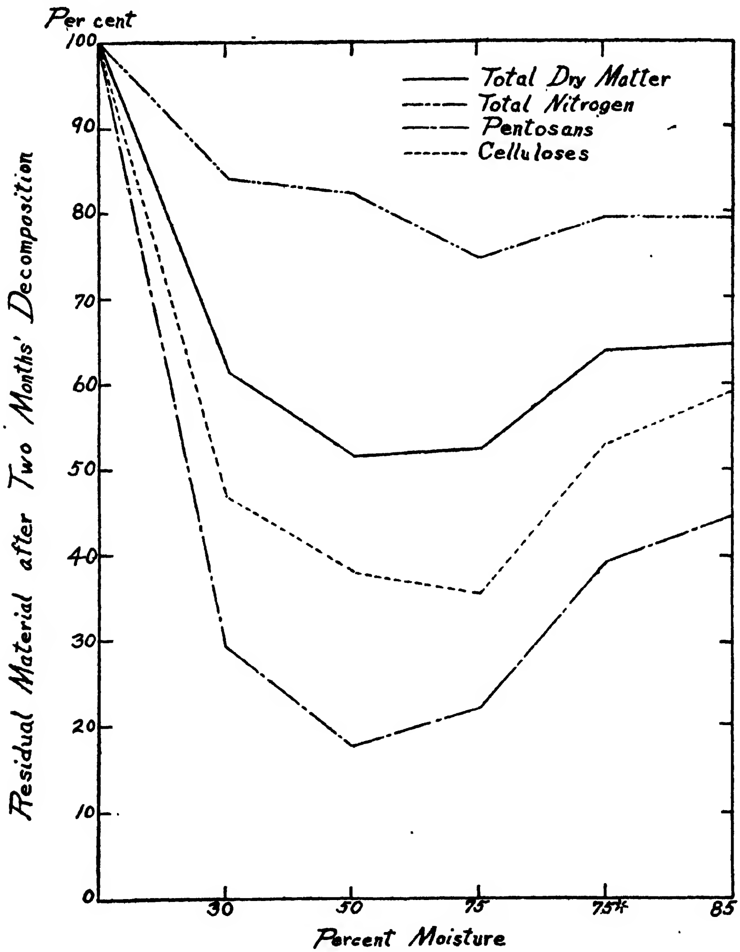


FIG. 1.—The influence of moisture and aeration upon the decomposition of fresh horse manure (Egorov).

*The manure was allowed to decompose in an atmosphere of $CO_2$.

Within a period of ten days the sheep consumed 8,640 grams of the foodstuffs (a little over four times as much timothy hay as rolled oats) and produced 6,448 grams of wet manure, equivalent to 2,761

grams of dry manure. The chemical composition of the feed and the manure is given in Table 2.

TABLE 2.—*Chemical composition of the foodstuffs consumed by sheep and of the manure produced.*

| Chemical constituents | In timothy | In oats | In total feeds | In manure | Consumed by sheep | |
|---|---|---|---|---|---|---|
| | *Grams* | *Grams* | *Grams* | *Grams* | *Grams* | % |
| Ether-soluble substances | 78.5 | 134.4 | 212.9 | 46.1 | 166.8 | 79.3 |
| Cold-water-soluble substances | 920.5 | 63.4 | 983.9 | 502.1 | | |
| Cold-water-soluble sugars | 441.1 | 0 | 441.1 | 0 | 441.1 | 100.0 |
| Hemicelluloses and starches | 1,239.2 | 461.7 | 1,700.9 | 510.8 | 1,190.1 | 70.0 |
| Celluloses | 2,484.7 | 4.1 | 2,488.8 | 516.3 | 1,972.5 | 79.7 |
| Lignins | 602.4 | 93.2 | 695.6 | 560.5 | 131.1 | 24.1 |
| Nitrogen (recorded as protein) | 402.8 | 283.1 | 685.9 | 704.1 | —— | —— |
| Total ash | 371.3 | 34.3 | 405.6 | 474.9 | | |

These results show that the sheep consumed 70 to 80% of all the fats, starches, hemicelluloses, and celluloses, and all of the water-soluble sugars. The fact that only 51% of the water-soluble material is found again in the manure does not indicate at all that only 49% of this group of feed constituents has been consumed by the sheep, but because the urine has been included in the manure it has tended to increase appreciably the content of water-soluble substances produced as a result of the digestion processes of the animals. The lignins have been consumed less than any other group of chemical constituents of the feeds, their abundance in the manure thus tending to increase appreciably over that found in the original feeds. All the nitrogen consumed in the foodstuffs has been excreted in the manure, due to the fact that the sheep, being confined in closed pens, have even lost some body weight, thus increasing the nitrogen content of the excreta as a result of the endogenous metabolism of the animals.

It is interesting to note, however, that, while practically all the nitrogen in the feeds was in the form of proteins, there was a large increase in the water-soluble nitrogen in the manure. The ash content of the manure has also increased over the ash content of the feed due to the fact that the salt consumption by the animals was not recorded.

The chemical composition of the sheep manure resulting from these feeding experiments, as compared with that of horse and cow manure, is given in Table 3. The analyses were made on pure excreta, including the urine in the case of the sheep manure and to some extent in the case of the cow manure. This makes the nitrogen

content and the amount of water-soluble materials in these manures considerably higher than in the case of the horse manure. The lower lignin content in the horse manure may indicate greater utilization of this chemical complex by this animal or a different chemical composition of the feed consumed.

TABLE 3.—*Chemical composition of various fresh manures, litter-free, on percentage basis of dry material.*

| Chemical constituents | Sheep manure* | Horse manure† | Cow manure* |
|---|---|---|---|
| Ether-soluble substances | 2.83 | 1.89 | 2.77 |
| Cold-water-soluble organic matter | 19.19 | 3.19 | 5.02 |
| Hot-water-soluble organic matter | 5.73 | 2.39 | 5.32 |
| Hemicelluloses | 18.46 | 23.52 | 18.57 |
| Celluloses | 18.72 | 27.46 | 25.23 |
| Lignins | 20.68 | 14.23 | 20.21 |
| Total nitrogen | 4.08 | 1.09 | 2.38 |
| Ash | 17.21 | 9.11 | 12.95 |

*Solid and liquid excreta.
†Solid excreta only.

## EXPERIMENT 2

This experiment deals with the decomposition processes which manure undergoes in composting. For this purpose, the sheep manure obtained in the previous experiment was employed. The conditions were not comparable to those that would take place in exposed piles or in soil, but the results may be interpreted better due to the carefully controlled conditions. Three-hundred-gram portions of the air-dried manure (containing the urine) were placed in a series of earthenware pots. Enough water was added to bring the

TABLE 4.—*Influence of moisture on the decomposition of sheep manure in 192 days at 21°C.*

| Chemical constituents | Percentage of dry material | | |
|---|---|---|---|
| | Original manure | Decomposed manure | | |
| | | 100% moisture | 200% moisture | 400% moisture |
| Total ash | 17.21 | 17.46 | 19.23 | 19.19 |
| Total nitrogen | 4.08 | 3.24 | 3.39 | 3.02 |
| $NH_3$-N | 0.93 | 0.11 | 0.13 | 0.09 |
| $NO_3$-N | 0 | 0.09 | 0 | 0 |
| Ether-soluble substances | 2.83 | 2.38 | 2.58 | 2.97 |
| Cold-water-soluble substances | 19.19 | 8.40 | 11.40 | 9.08 |
| Hot-water-soluble substances | 5.73 | 4.28 | 6.49 | 6.53 |
| Hemicelluloses | 18.46 | 9.14 | 7.31 | 11.62 |
| Lignins | 20.68 | 20.72 | 27.31 | 22.78 |
| Celluloses | 18.72 | 16.05 | 12.79 | 16.95 |

moisture to 100, 200, and 400%. The pots were incubated at room temperature and were not inoculated otherwise in order to allow the natural intestinal flora to bring about any further decompo-

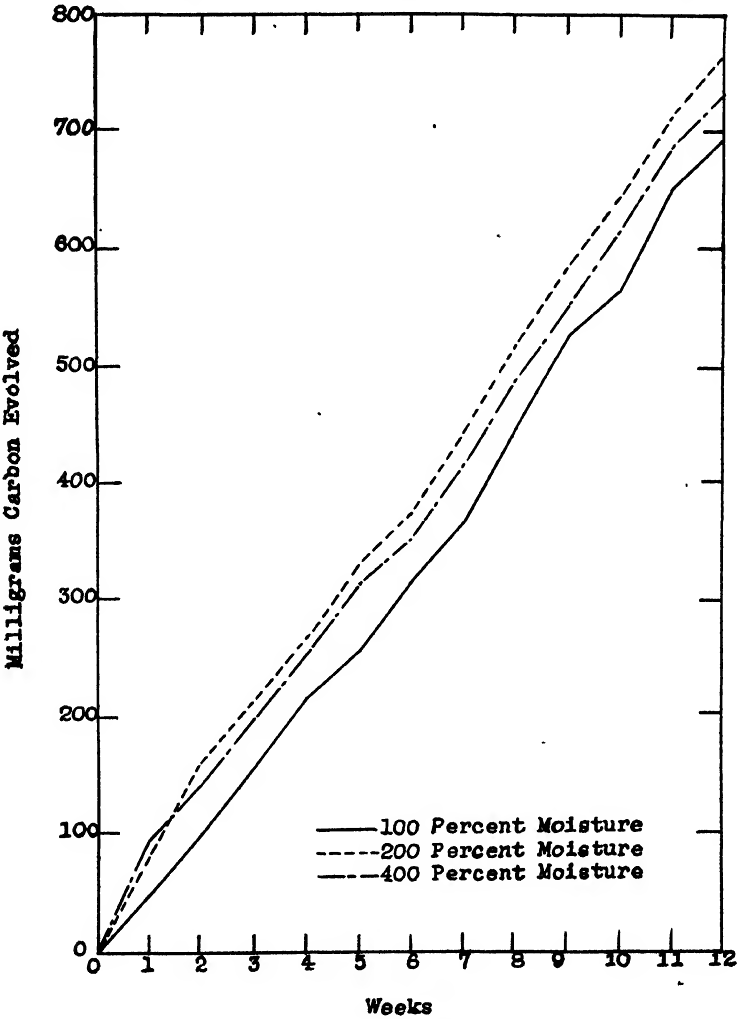


FIG. 2.—Evolution of carbon dioxide in the decomposition of sheep manure at different moisture contents.*

sition. At various intervals of time the material was analyzed, according to one of the methods outlined elsewhere (12).

The results given in Table 4 show that the decomposition of the sheep manure at room temperature was rather slow. The greatest

reduction of celluloses and hemicelluloses took place at 200% moisture. This was accompanied, also at this moisture, by an increase in the lignin content. The ammonia rapidly disappeared, while nitrate was formed only at the lowest moisture content. Nitrogen was lost in all cases. The cold-water-soluble substances were rapidly decomposed. Even the 400% moisture did not fully saturate the manure, hence no anaerobic conditions were produced.

## EXPERIMENT 3

The decomposition of the same sheep manure was studied. Ten-gram quantities were placed in flasks which were incubated at 27°C. The evolution of $CO_2$ was measured as an index of decomposition. The manure was inoculated in this case with a soil suspension. The decomposition of the manure was most rapid at 200 and at 400% moisture, especially during the early stages. The direct losses of ammonia at the various moisture contents were determined by absorbing the gases in standard sulfuric acid solution. These amounted in 18 weeks to 6.16 mgm at 100% moisture, to 9.18 mgm at 200% moisture, and to 2.78 mgm at 400% moisture, showing that the smallest losses of nitrogen as ammonia occurred with the highest moisture content and that the greatest losses of ammonia took place when the moisture (200%) was just optimum for the aerobic decomposition of the manure.

To throw further light upon the bacteriological and chemical processes involved in the decomposition of manure during composting, fresh horse manure was used. This manure contained 70.5% moisture and 29.5% dry matter. Enough manure to give 24 pounds of dry material was placed in galvanized iron cans. These were kept in a greenhouse for a period of 290 days with an outside temperature of about 18 to 23°C. At various intervals, the compost was mixed and portions taken for chemical analysis. At the end of 290 days, the composted manure was found to contain 81.6% moisture and 18.4% dry matter, with a total of 9.55 pounds of dry material. The results of the relative composition of the manure at the different dates of sampling and the total abundance of the various constituents are given in Tables 5 and 6.

These results show that in the decomposition processes involved in the composting of the manure there is a gradual reduction of all the organic complexes, especially of the celluloses and hemicelluloses which make up most of the bulk of the material that has undergone decomposition. The lignins as well have decomposed but to a considerably less extent than the other two groups of complexes.

TABLE 5.—*Composition of horse manure at different stages of decomposition on percentage basis of dry material.*

| | Fresh | 39 days | 96 days | 157 days | 290 days |
|---|---|---|---|---|---|
| Ether-soluble fraction | 1.89 | 1.89 | 1.47 | 0.88 | 0.95 |
| Cold-water-soluble fraction | 3.19 | 4.11 | 4.73 | 4.36 | 3.81 |
| Hot-water-soluble fraction | 2.39 | 3.86 | 3.37 | 2.19 | 1.90 |
| Hemicelluloses | 23.52 | 22.84 | 15.76 | 13.36 | 12.67 |
| Celluloses | 27.46 | 23.18 | 16.07 | 6.98 | 5.97 |
| Lignins | 14.23 | 16.63 | 17.92 | 20.54 | 28.43 |
| Crude protein | 6.81 | 7.00 | 14.81 | 18.56 | 16.38 |
| Ash | 9.11 | 13.64 | 20.93 | 22.22 | 19.32 |

TABLE 6.—*Decomposition of the various organic complexes in horse manure within 290 days.*

| Organic complexes | Original manure in grams | Residual compost in grams |
|---|---|---|
| Total dry material* | 10,800.0 | 4,300.0 |
| Ether-soluble fraction | 204.1 | 40.9 |
| Cold-water-soluble fraction | 344.5 | 163.8 |
| Hot-water-soluble fraction | 258.1 | 81.7 |
| Hemicelluloses | 2,540.2 | 544.8 |
| Celluloses | 2,965.7 | 256.7 |
| Lignins | 1,536.8 | 1,223.5 |
| Crude protein | 735.5 | 704.3 |

*Including the mineral constituents or ash.

The relative cellulose concentration has diminished from 27.46% in the fresh manure to 5.97% in the composted manure, and the total cellulose has diminished from the original 2,965.7 grams in the fresh manure to 256.7 grams in the composted manure. The hemicelluloses have diminished from 23.52% in the fresh manure to 12.67% in the composted manure, while the total hemicellulose decreased from 2,540.2 grams to 544.8 grams. The lignins, however, increased from 14.23% in the fresh manure to 28.43% in the composted manure, and the total amount decreased from 1,536.8 grams to 1,223.5 grams, a very small reduction indeed when compared with that of the celluloses and hemicelluloses.

The protein content of the manure increased rapidly with a decrease in the celluloses and hemicelluloses; however, after 157 days, when the decomposition of these carbohydrates reached a maximum, the proteins as well began to undergo a certain decomposition. This is due to the fact that, when the decomposition of the celluloses and hemicelluloses kept up at a high rate, the ammonia liberated from the decomposition of the proteins was immediately reassimilated by the micro-organisms and fresh proteins were synthesized. As soon as the available nitrogen-free organic complexes have reached a min-

imum, the micro-organisms were unable to reassimilate all the ammonia liberated from the protein decomposition, and considerable losses of nitrogen occurred. However, even after 290 days of composting of the manure, the proteins have decreased only from 735.5 grams to 704.3 grams.

In the fresh manure there was less hemicellulose than cellulose, but in the composted manure there was left more than twice as much of the first than of the second group of carbohydrates. This bears out the results reported previously (14) that, although some of the hemicelluloses decompose more rapidly than the celluloses, others are more resistant to decomposition and accumulate. This is further increased by the hemicelluloses synthesized by the micro-organisms.

The results presented in these studies definitely point to the processes taking place in the decomposition of stable manure. The transformation of the nitrogen cannot be dissociated from the decomposition of the non-nitrogenous organic complexes, especially the celluloses and hemicelluloses.

As to the rôle of micro-organisms in the decomposition and transformation of manure, it is sufficient to point to the recent results of Ruschmann (13) and others, as well as to the studies carried out in this laboratory, to come to the general conclusion that all these processes are microbiological in nature. Decomposition of the sugars, of the hemicelluloses and celluloses, of the urea and the proteins, and even of the fats and the lignins, on the one hand, and the synthesis of microbial cell substance, which may be quite considerable, on the other, are the two important groups of functions of the micro-organisms active in the decomposition of manure, either added directly to the soil or first composted.

One more phase of the subject remains to be discussed, namely, the preservation of the manure. As shown in the above tables, large losses of nitrogen occur in the composting of manure, especially under aerobic conditions. Numerous contributions have been made to this subject, which is fairly well understood at the present time, and the proper methods of control are available. It is sufficient to call attention here to some of the processes which lead to the losses and the principles underlying their prevention.

The transformation of the nitrogen in the urine is so rapid that it can nearly all be converted within a period of 48 hours into ammonium compounds. Since the nitrogen present in the urine makes up as much as half of the total nitrogen in the manure and since the decomposition of the celluloses may be delayed for a certain time in the composting of manure, this form of nitrogen represents one im-

portant source of losses through direct volatilization. If the decomposition of the celluloses would only set in quickly enough, the nitrogen in the form of ammonia would immediately be assimilated by the micro-organisms bringing about cellulose decomposition and thus transform the nitrogen into organic complexes. The alkaline reaction due to the formation of ammonium carbonate may also have something to do with the delay in the decomposition of the celluloses. Even when the decomposition of these carbohydrates sets in, it requires considerable time before all the available nitrogen in the urine can be used up.

Another source of nitrogen losses is found in the activity of the nitrifying and denitrifying bacteria as shown by Niklewski (11).

The problem of conservation of manure thus reduces itself to preventing the losses of ammonia. This can be accomplished by the addition of acid-reacting or buffering substances, such as superphosphate or sulfuric acid, while in some cases sulfur has been recommended. By hastening the process of decomposition of the carbohydrates in the manure, the conversion of the ammoniacal and other water-soluble nitrogen in the manure into insoluble forms through the activities of the micro-organisms is speeded up. The so-called "Edelmist" process of Krantz, which consists in hastening the decomposition of the carbohydrates until a temperature of 65°C has been attained, is also directed towards preventing the losses of nitrogen from the manure.

To prevent any loss through denitrification or the reduction of nitrates to atmospheric nitrogen in the compost, it is sufficient to prevent the process of nitrification from taking place. This can be done either by preventing the inoculation of the manure with nitrifying bacteria, by making conditions anaerobic, or by adding acid-reacting substances or disinfectants to stop the development of these bacteria.

## DISCUSSION

The nature of the problems involved in the decomposition of organic matter in stable manure, whether this is first composted or applied directly to the soil, presents certain specific differences from those involved in the decomposition of green manures or in the preparation of artificial manures.

First of all, the very nature of the chemical complexes after they have gone through the digestive tract of animals has become materially modified. The animals, either through the action of their digestive enzymes or through the agency of bacteria living in their digestive tracts, have consumed all the sugars and starches and a

large part of the fats, pentosans, and celluloses. The manure has become enriched in lignins and in proteins.

Secondly, the nature of the nitrogenous compounds is quite distinctly different from that of similar compounds in the other organic manures previously considered. As a result of the digestive processes in the animals, practically a half of the nitrogen is excreted in an available or readily available form. If this nitrogen is not immediately used by plants, it may be rapidly lost, unless other measures are taken for its preservation.

These problems can be briefly summarized as follows:

Manure is a product resulting from the digestion by animals of feed materials largely of plant and some of animal origin. The digestion of the complex organic materials in the feeds involves a diminution of sugars, starches, fats, pentosans, and celluloses, and an increase of the lignins. The nitrogen is excreted by the animal partly in a soluble form, as urea and ammonium carbonate, and partly in a complex organic form, some of which is made up of bodies of micro-organisms.

In the decomposition of manure, the pentosans and celluloses are reduced much more rapidly than the total organic matter, while the lignins are decomposed less rapidly, hence there is a rapid reduction of the polysaccharides and an accumulation of the lignins.

Only the soluble nitrogen undergoes rapid nitrification in the soil. When the decomposition of the organic matter begins, a part of the soluble nitrogen is changed by the micro-organisms into a complex organic form. Both forms of organic nitrogen, namely, that present originally in the manure and that synthesized by the micro-organisms in the composting of the manure, become only slowly available.

The rôle of micro-organisms in the transformation of manure can be summarized under the processes of decomposition and synthesis both of which take place side by side. From the most readily decomposable sugars to the most resistant lignins all the organic complexes in the manure are acted upon by micro-organisms in the decomposition of the manure. Parallel with the decomposition processes, the micro-organisms synthesize considerable cell substance, as evidenced by the increase in the protein content, which may form a large part of the actual manure after it has been composted.

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# THE PRESENCE OF RHIZOBIUM ON AGRICULTURAL SEED[1]

J. K. WILSON[2]

Probably all agricultural seeds have on them some form of microscopic life. Sometimes it is a harmless organism, while at other times it may be parasitic in nature. Such an organism as *Pseudomonas campestris* may be found on cabbage seed, while the fungus that causes anthracnose may be found on beans. Many other instances could be cited. Some attempts have been made to isolate the legume organism from seed. Prucha[3] studied the bacterial flora of several samples of alfalfa seed. He found a great many organisms on the seed, fresh seed having more than older ones, but failed to find an organism that could be recognized as the legume organism. The present paper is a report of work done to determine the presence or absence of this organism on various agricultural seeds.

## TECHNIC

After numerous attempts to isolate the legume organism from agricultural seed by the "plate method," it was abandoned and another method used. This consisted essentially of washing seeds with sterile water and then using the washings to inoculate sterile soil. The legume organism, if present, will increase in numbers in its new surroundings. The soil was then sown with seed of the desired host plant, and after a suitable growth period the plants were examined for nodules. The presence or absence of nodules on such plants was the criterion of the presence or absence of the organism on the seed. The exact procedure follows.

### OBTAINING SEED SAMPLES FOR ANALYSIS

Numerous samples of various agricultural seed were collected. These were kept in paper bags in the laboratory until examined. Some of the seeds were not over 90 days old while others were several years old, although it is not always certain that the exact age of the seed as obtained was correct.

### OBTAINING BACTERIA FROM SEED BY WASHING

It is conceivable that only a very few seeds in a very large sample may have on them the legume organism. It was considered impractical, therefore, to plant enough seed to determine the presence of the

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[3]Prucha, M. J. The persistence and vitality of bacteria on alfalfa seed. Abs. in Science, 35:229. 1912.

organism by the process of nodulation. It seemed more logical to wash the seed and to use the washings as inoculating material. To do this they were washed with sterile water. For each 100 grams of seed about 110 cc of water were used. After thoroughly agitating the seed, the water was drained off through cheesecloth. The water was used to moisten the sterile soil in which the host plant was to be grown.

### PRODUCING NODULES ON HOST PLANTS

To make certain that nodulation could be traced to bacteria which came from the seed, it was necessary to grow the host plant in such a manner that it would not become contaminated with legume bacteria. To do this a suitable quantity of air-dry soil (about 300 grams) was placed in a test tube 6 x 50 cm. This was plugged with cotton. The desired number for use with each sample of seed was thus prepared and sterilized. Enough of the water which was obtained from washing the seed was added to the soil to make conditions suitable for germination and growth of the plantlets.

The washings which were used to moisten the soil may have had only one or two legume organisms in them. As nodule production is probably a chance contact between the host plant and the nodule organism, it may be that if the soil in the tubes were planted immediately with the desired host plant seed, nodulation would be delayed. Consequently, the containers were allowed to stand for 10 to 14 days before planting. This incubation period should have permitted the establishment of a high legume bacteria content provided the organism was present. After this period the desired host plant seed was introduced.

Since representatives of several groups of the legume bacteria may be carried on agricultural seed, it seemed feasible to plant the seed of several host plants together in the same test tube. It is believed that this precedure in no way vitiated the results. As a further precaution that the results may be reliable, it was necessary partially to sterilize the legume seed before planting. This was done by treating the seed with a solution of calcium hypochlorite. After treatment the excess solution was drawn off and the moist seed transferred to the surface of the soil in the test tubes. At least 100 tubes prepared for use in this work have been used as checks and in no case did nodule formation occur.

Previous observations on nodulation by this method have shown that 10 to 14 days is sufficient time for nodules to develop on *Vicia villosa*, *Trifolium pratense*, and *Soja max*, while a longer period, about 21 days, is better for *Medicago sativa*. Therefore, after a

suitable growth period, the plant roots were carefully washed and placed in water under good illumination so that any nodules could be readily seen. *Vicia villosa* was used as the host plant for the organisms of the Pisum group, *Medicago* for those of the Medicago group, and *Trifolium pratense* for those of the Trifolium group.

## RESULTS

In November, 1926, samples of seed were collected in the open market. These comprised 10 pounds of alfalfa (*Medicago sativa*), 1925 crop; 10 pounds of alsike clover (*Trifolium hybridum*), 1925 crop, and 5 pounds of the 1926 crop; and 10 pounds each of sweet clover (*Melilotus alba*) and red clover (*Trifolium pratense*) of the 1925 crop. These samples were handled as previously outlined. The production of nodules on *Tr. pratense* and on *V. villosa* is shown in Table 1.

TABLE 1.—*Presence of legume organism on seed as indicated by nodule production on Trifolium pratense and on Vicia villosa.*

| Seed | Number of tubes planted | Number of tubes with nodules on plants of *Tr. pratense* | *V. villosa* |
|---|---|---|---|
| 1926 *Tr. hybridum* | 20 | 20 | 0 |
| 1925 *Tr. hybridum* 8313 | 30 | 20 | 18 |
| 1925 *Tr. pratense* | 20 | 19 | 4 |
| 1925 *Melilotus alba* | 20 | 12 | 1 |
| 1925 *Medicago sativa* | 20 | 12 | 5 |

Since the production of nodules is the criterion for the presence of the legume bacteria on the seed, it is evident from Table 1 that legume seeds may carry legume bacteria not only for the particular group represented by the seed but also for other groups. Alsike clover seed (*Tr. hybridum*) of the 1925 and 1926 crops seemed to carry a rather large number of the legume bacteria of the Trifolium group. The 1925 seed, however, did not carry the organism of the Pisum group, while the former carried both. It should be mentioned, however, that it is not certain that this sample of seed had such organisms even when freshly grown. Red clover seed (*Tr. pratense*) carried the organism of both the Trifolium and the Pisum groups. Tests were also made from the washings of alfalfa seed (*Medicago sativa*), but no positive results were obtained.

These data suggested that the age of the seed may be a factor in the longevity of the legume bacteria on them. To test this *V. villosa* seed produced in 1920, 1923, 1924, and 1925 were collected. These seeds were examined in December, 1926, for two groups of legume bacteria. The results are given in Table 2.

TABLE 2.—*Presence of legume organism on Vica villosa seed of different ages as indicated by nodule production on Vicia villosa and on Trifolium pratense.*

| Age of seed, years | Quantity examined, grams | Number of tubes planted | Number of tubes with nodules on plants of | |
|---|---|---|---|---|
| | | | *V. villosa* | *Tr. pratense* |
| 6 | 500 | 6 | none | none |
| 3 | 550 | 5 | none | 1 |
| 2 | 520 | 4 | 1 | 1 |
| 1 | 550 | 4 | 1 | 3 |

Although it is not certain that the various lots of vetch seed from which the data in Table 2 were obtained were all uniformly inoculated at the beginning of storage, yet it is evident that the older seed had fewer legume bacteria on them than the young seed. Vetch and red clover plants grown in 23 tubes which received no washings from the seed produced no nodules.

Other seeds were examined. The organism for nodule production on *Tr. pratense* was found on new seed of the following: Heinrich's rye, Silver Hull buckwheat, Marquis wheat, Cornellian oats, and timothy; and on one-year-old seed of Upright oats, Alpha barley, sweet clover, and Grimm alfalfa. Also, the organisms for nodule production on *V. villosa* were found on new seed of the following: Heinrich's rye, Cornellian oats, and timothy; and on seed one year old of Upright oats, Cornellian oats, timothy, and sweet clover. This latter organism, however, was not found on seed of new Marquis wheat, one-year-old Alpha barley, Japan millet probably two years old, Manchu soybean one year old, field bean two years old, Japan clover probably two years old, peanut in hulls, burr clover in burrs, or Grimm alfalfa. Also, certain samples of seed failed to carry the organism capable of producing nodules on *Tr. pratense*.

## DISCUSSION

It is evident from the results of this study that agricultural seed are frequently carriers of legume bacteria. This seems entirely logical since seed are grown and handled under such conditions that they can hardly escape coming in contact with the soil flora. From this point on it is merely a question of survival. If conditions are suitable the organism may survive for several years, if not they may last only for a short time. While it is not certain that all the samples examined had the legume bacteria at the beginning of storage, it is quite evident that they were exposed to such contamination as the soil offered. Probably such factors as desiccation and aging of the seed aided in their disappearance. These results will offer one very definite explanation for the frequent observation that where a legume

crop is being grown for the first time without artificial inoculation there is a spattering of seedlings with nodules on their roots.

## SUMMARY

Legume and nonlegume seed were collected and examined for the presence of the legume organism. Each sample was washed and the washings used to moisten sterile soil in which was grown a desired host plant. The production of nodules on the host plant was taken as the criterion of the presence of the legume organism.

Fresh legume seed examined by this method may, and usually do, have on them the legume organism. Old seed are less liable to have the organism than fresh seed. It often happens that the seed carry the organisms for several species of legumes. In certain cases an examination of 500 grams of seed did not reveal the organism, while in others 25 grams were all that was necessary. Also nonlegume seed, such as oats, timothy, etc., may carry legume bacteria representative of several species.

# ACIDITY CHANGES IN STORED LEGUME SEEDS[1]

J. K. Wilson[2]

While making a study of agricultural seeds as carriers of legume bacteria, it was noted that, as a rule, seeds several years old had fewer legume bacteria on them than fresh seeds. Two causes were thought to contribute to this condition. On one hand, desiccation is known to reduce greatly the germ content of soil and it may reduce it on seeds. On the other hand, aging of seeds may produce products that act as germicides. Some preliminary tests indicated that legume seeds several years old were more acid than fresh seeds. Acidity studies were made, therefore, of legume seeds of varying ages, hoping that the resulting data might offer an explanation for the fact that older seeds as a rule have fewer legume bacteria on them than fresh seeds, and also suggest an explanation for the repeated failures to get satisfactory inoculation from stored artificially inoculated seeds.

It is possible that not only the surface but also the interior of the seeds may change in acidity during storage. Preliminary tests in which the whole seeds and a meal made from the seeds were tested for acidity after three minutes and after twenty minutes in contact with water indicated that the meal gave more consistent pH readings than the whole seeds. The seed surfaces undoubtedly carry extraneous materials which may vary somewhat with every sample that is being tested. To reduce this possible irregularity to a minimum, seeds were prepared for acidity tests by grinding. To 10 grams of the meal was added about 20 cc of boiled distilled water which had been cooled over soda-lime. This usually made a slush. After standing three minutes readings were made by means of the quinhydrone-platinum electrode.

Early in 1928 legume seeds of various species were collected. No effort was made to learn their previous storage conditions. Only the year in which they were supposed to have been grown was recorded. Undoubtedly, some of the seed were drier than others at the beginning of storage and some were stored in a drier situation than others. These conditions govern respiration which in turn contributes to the aging of seeds. Thus it is logical to expect some irregularities when one is trying to class the seed samples as old or as fresh when designating them by years.

[1]Contribution from the Department of Agronomy, Cornell University, Ithaca, N. Y. Received for publication March 4, 1929.

[2]Professor of Soil Technology.

It will be noted in Table 1 that there is every indication that aging is accompanied by a change in acidity. Seeds of *Vicia villosa* grown in 1927 had a reaction of pH 6.28, while seed grown in 1920 had a reaction of pH 5.85. An increase in acidity as the seeds become older was also noted for *Phaseolus*, *Soja max*, *Trifolium pratense*. *Melilotus alba*, and *Medicago sativa*. Scarlet runner (*Ph. multiflorus*) seeds and horse bean (*V. faba*) seeds do not appear to increase in acidity, but suggest no change or possibly a slightly more alkaline one as the seeds become older.

TABLE 1.—*Acidity changes in stored legume seeds, 1927.*

| Seed | Year grown | pH | Seed | Year grown | pH |
|---|---|---|---|---|---|
| *V. villosa* | 1927 | 6.28 | *Tr. pratense* | 1927 | 6.32 |
| | 1927 | 6.30 | | 1926 | 6.27 |
| | 1926 | 6.06 | | 1925 | 5.99 |
| | 1925 | 6.05 | | | |
| | 1924 | 5.96 | *Melilotus alba* | 1926 | 6.30 |
| | 1923 | 5.87 | | 1924 | 6.11 |
| | 1920 | 5.85 | | | |
| | | | *Medicago sativa* | 1926 | 6.25 |
| *Phaseolus* spp | 1927 | 6.70 | | 1926 | 6.23 |
| | 1926 | 6.65 | | 1926 | 6.09 |
| | 1925 | 6.66 | | 1925 | 6.58 |
| | 1925 | 6.53 | | 1924 | 6.08 |
| *Soja max* | 1927 | 6.78 | Scarlet runner | 1927 | 5.99 |
| | 1926 | 6.55 | (*Ph. multiflorus*) | 1925 | 5.99 |
| | 1925 | 6.48 | | 1925 | 6.26 |
| | 1924 | 6.30 | | | |
| | | | Horse bean (*V. faba*) | 1926 | 6.10 |
| | | | | 1925 | 6.28 |
| | | | | 1924 | 6.31 |

Seeds of pea bean whose exact age and storage conditions were known were also tested. These were furnished by W. O. Gloyer. Some of them were grown in 1917. At that time beans of the same lot were stored under different conditions. One lot was kept in an open jar in the laboratory. These when examined in 1928 gave a reading of pH 5.87. Another lot was kept in a sealed jar over calcium chloride and when examined in 1928 gave a reading of pH 6.33. In another case beans were stored in an open jar in the laboratory in 1921. In 1928 the reading was pH 6.12. A lot of the same seed kept over calcium chloride and examined in 1928 gave a reading of pH 6.38. Well's hardshell beans that were grown in 1927 were selected and stored. One lot had a high moisture content as determined by softness of beans. These were stored in a burlap bag

out-of-doors. In 1928 a reading of pH 6.47 was obtained. Another lot with low moisture content was stored in the laboratory, and in 1928 a reading of pH 6.53 was obtained.

In one experiment seeds were artificially aged. They were moistened with distilled water, enough being added to dampen each seed but not enough to permit soaking. After this treatment they were spread out to dry. This is about the same method that is used when artificial cultures are applied. Readings of pH were made both before and four days after treatment. At the end of the four-day period the seeds appeared to be about as dry as they were before being moistened. The results are recorded in Table 2.

TABLE 2.—*Reaction of seeds before and after wetting, determinations four days apart.*

| Seed | pH of seed Before | After |
|---|---|---|
| Alfalfa (*Medicago sativa*) | 6.49 | 6.30 |
| Sweet clover (*Melilotus alba*) | 6.96 | 6.81 |
| Red clover (*Tr. pratense*) | 6.49 | 6.26 |
| Alsike clover (*Tr. hybridum*) | 6.49 | 6.38 |
| Manchu (*Soja max*) | 6.37 | 6.37 |

## DISCUSSION

The pH readings of legume seeds of various ages, though not extensive, seem to be sufficient to indicate that aging of seed is accompanied by a change in reaction. In most samples that have been examined this change has been an increase in acidity. While no attempts have been made to determine what the products are that have contributed to this change, it is believed that they may have some bearing on the longevity of legume bacteria on the seed. This applies not only to the bacteria naturally accompanying seeds, but also to those that may be added as artificial cultures in an attempt to inoculate for crop production. In most cases seed inoculation is accompanied by enough moisture to dampen each seed. This starts respiration which causes a change in what may be called a carbon-salt ratio. This starting and stopping of respiration whether rapid for a few hours or very slow over a period of several years probably results in the same type of end products, the net result being in most cases an increase in acidity.

## CONCLUSION

Seeds of different species of legumes, ranging from fresh seed to seeds 10 years old, have been tested for acidity. In most cases there has been a marked change in reaction. Usually older seeds of a given legume have a more acid reaction than fresh seed.

# MOISTURE CONTENT OF FLAXSEED AND ITS RELATION TO HARVESTING, STORAGE, AND CRUSHING[1]

A. C. DILLMAN AND R. H. BLACK[2]

## INTRODUCTION

The modern combined harvester and thresher has been used with marked success during the past two or three years in harvesting flax in Montana and the Dakotas. This new use of the combine has brought out the importance of the moisture content of flaxseed in relation to harvesting, storage, and crushing. The observations and tests made by the writers during the past two years may be of interest to agronomists in the flaxseed-producing states.

The authors wish to express their obligation to M. L. Wilson of Montana for his kind cooperation in obtaining the data presented from Fairway Farms near Brockton, Mont., to T. E. Stoa for the data from North Dakota, and to A. C. Arny for the data from Minnesota. Thanks are due also to R. B. Tootell, who had direct charge of the sampling at Brockton, Mont., and to R. S. Dunham, who obtained the samples at Crookston, Minn.

## MOISTURE CONTENT DURING GROWTH

The growing young flaxseed contains a high percentage of moisture, which is gradually reduced as the seed develops toward maturity. In the growth of the seed there is a more or less steady increase in dry weight coincident with a decrease in moisture content. In studies made at University Farm, St. Paul, Minn., in 1926 and 1927, the moisture content of flaxseeds ranged from 85% in seeds 1 to 5 days old, that is, that number of days after flowering, to 22% in seeds 40 to 42 days old.[3] This is shown graphically in Fig. 1. When the seeds were fully developed, that is, when the deposition of oil and other plant food material ceased, as indicated by lack of further increase in dry weight and by the detachment of the seed at the hilum from the supporting placental thread, they still contained from 30 to 40% of moisture.

[1]Contribution from Office of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture, Washington, D. C. Received for publication March 8, 1929.

[2]Associate Agronomist in Charge of Flax Investigations, Office of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture, and Senior Marketing Specialist, Grain Division, Bureau of Agricultural Economics, U. S. Department of Agriculture, respectively.

[3]DILLMAN, A. C. Daily growth and oil content of flaxseeds. Jour. Agr. Res., 37:357-377. 1928.

The ripening process, covering a period of a few days to two weeks, according to the weather conditions, consists chiefly in loss of moisture. There was a marked loss of moisture during the last five or six days of the ripening period, after the seeds had reached a uniform dry weight indicating that their growth was completed.

## LOSS OF MOISTURE DURING RIPENING

After the growth of the flax seed is completed, the ripening process is chiefly a matter of dehydration or drying of the seed. This drying process proceeds very rapidly under favorable climatic conditions.

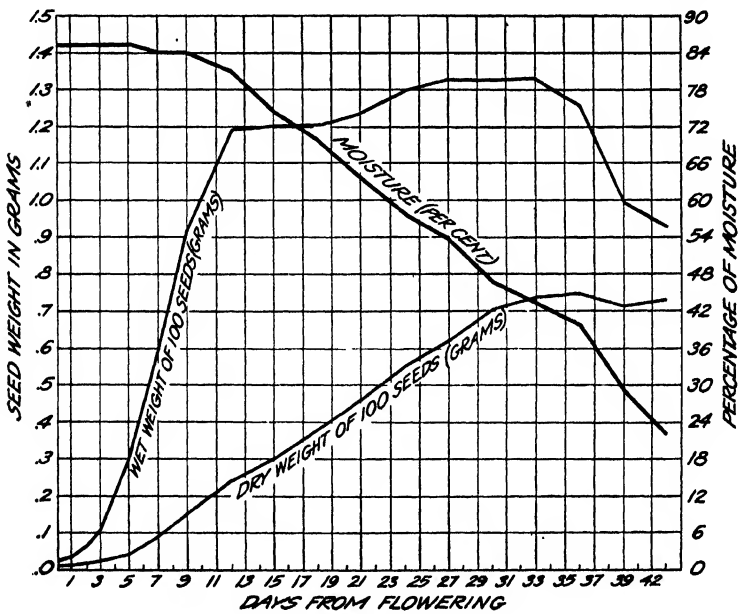


FIG. 1.—Average weight and dry weights and percentage of moisture in flaxseeds from flowering to maturity at University Farm, St. Paul, Minn., in 1926 and 1927.

It proceeds faster, no doubt, in the drier atmosphere of the northern Great Plains than in the more humid eastern portion of the flax area.

At St. Paul, as mentioned above, there was a rapid loss of moisture during ripening, amounting to 24% in a period of five days in 1926, and 16% in a period of six days in 1927. Unfortunately, the sampling was not continued after the 42nd day from flowering, at which time the seeds still contained 22% of moisture.

The moisture content of flax seeds collected during a period of seven days, from August 27 to September 2, 1928, at Mandan, N.

Dak., is shown in Table 1. The plants were pulled at the hours indicated and the seeds threshed out and weighed immediately. Samples of from 60 to 112 grams of seed were obtained. At the beginning of the test, on August 27, the plants were barely ripe enough to harvest with a binder or reaper. The bolls, stems, and leaves were brown, but not dry. By September 2 the plants were fully ripe, but still hardly dry enough to be harvested with a combine. On the afternoon of August 27 the seeds contained from 16 to 17% of moisture. On September 1 they contained 8.8%, a reduction of about 8% in moisture content during a period of five days.

TABLE 1.—*The moisture content of seeds of Linota flax, of whole flax bolls, and of chaff of bolls, from August 27, when flax plants were barely ripe enough to harvest with binder or reaper, to September 2, when plants were fully ripe, at Mandan, N. Dak., 1928.*

| Date | Hour | Temperature, °F | Relative humidity | Moisture content of Seeds | Bolls | Chaff |
|---|---|---|---|---|---|---|
| | | | % | % | % | % |
| Aug. 27 | 11 a.m.* | 55 | 82 | 15.9 | — | 37.2 |
| Aug. 27 | 1 p.m. | 55 | 82 | 17.0 | — | 34.8 |
| Aug. 27 | 3 p.m. | 55 | 82 | 16.3 | 23.0 | 26.8 |
| Aug. 28 | 7 a.m.† | 52 | 88 | 19.3 | 32.0 | 38.9 |
| Aug. 28 | 9 a.m. | 60 | 69 | 18.4 | 30.0 | 35.5 |
| Aug. 28 | 11 a.m. | 67 | 51 | 17.9 | 30.0 | 34.8 |
| Aug. 28 | 1 p.m. | 69 | 45 | 16.7 | 21.0 | 32.8 |
| Aug. 28 | 4 p.m. | 70 | 46 | 14.5 | 21.0 | 27.7 |
| Aug. 28 | 6 p.m. | 66 | 54 | 14.5 | 19.0 | 28.2 |
| Aug. 29 | 8 a.m.‡ | 58 | 83 | 16.6 | 23.0 | 32.2 |
| Aug. 31 | 6 p.m.§ | 73 | 48 | 9.0 | — | — |
| Sept. 1 | 6 a.m. | 66 | 50 | 10.3 | — | 26.2 |
| Sept. 1 | 9 a.m. | 70 | 49 | 10.3 | — | 21.8 |
| Sept. 1 | 1 p.m.** | 78 | 38 | 8.7 | — | 19.2 |
| Sept. 1 | 6 p.m. | 72 | 44 | 8.8 | — | 19.5 |
| Sept. 2 | 8 a.m.¶ | 57 | 67 | 9.2 | — | 17.2 |

*Six hours after rain of 0.23 inch. Day cool and cloudy with no wind.
†Heavy dew in morning. Day clear with gentle breeze.
‡Ten hours after rain of 0.1 inch. Night windy, partly cloudy, no dew.
§Night clear, trace of dew. Day clear, light northwest breeze.
**Strong breeze.
¶Partly cloudy, strong breeze, no dew.

It was observed that the whole bolls and the chaff of the threshed bolls appeared to be much more moist than the seeds. The moisture content of these, therefore, was determined, and the results are included in Table 1. On August 28 the moisture content of whole bolls ranged from 32% at 7 a.m. to 21% at 4 p.m., while that of the seeds ranged from 19.3% to 14.5%. The chaff from the threshed bolls contained 38.9% of moisture at 7 a.m. and 27.7% at 4 p.m.

This marked difference in moisture content between the seeds and the surrounding tissues of the boll suggests that the seeds may ripen earlier than the boll and more or less independently of it. A similar process occurs in the ear of corn when in the early ripe stage the grain is drier than the cob.

TABLE 2.—*The moisture content of flaxseed threshed by hand from standing flax and of flax bolls collected from standing flax and from windrows harvested September 4 on the Fairway Farm, Brockton, Mont., during the 10-day period, September 4 to 13, 1928.*

| Date | Hour | Temperature, °F | Relative humidity | Seed | Moisture in Bolls from Windrow* | Moisture in Bolls from Standing flax |
|---|---|---|---|---|---|---|
| | | | % | % | % | % |
| Sept. 4 | 6 p.m. | 73 | 55 | 9.0 | — | — |
| Sept. 5 | 7 a.m. | 44 | — | 8.0 | — | — |
| Sept. 5 | 10 a.m. | — | — | 8.0 | — | — |
| Sept. 5 | 12 m. | — | — | 7.0 | — | — |
| Sept. 5 | 2 p.m. | 73 | 51 | 6.8 | — | — |
| Sept. 5 | 4 p.m. | 70 | 53 | 8.0 | — | — |
| Sept. 5 | 6 p.m. | 66 | 63 | 7.0 | — | — |
| Sept. 6 | 7 a.m. | 54 | 82 | 8.9 | 13.2 | 8.4 |
| Sept. 6 | 12 m. | 90 | 28 | 8.0 | 6.7 | 8.0 |
| Sept. 6 | 5 p.m. | 82 | 35 | 6.0 | 4.6 | 6.0 |
| Sept. 7 | 7 a.m. | 55 | 82 | 5.2 | 7.8 | 8.3 |
| Sept. 9 | 8 a.m. | 48 | 80 | 9.0 | 10.9 | 13.2 |
| Sept. 9 | 4 p.m. | 50 | 81 | 8.8 | 7.6** | — |
| Sept. 10 | 3 p.m.† | 59 | 68 | 16.0 | 28.4 | 19.4 |
| Sept. 11 | 9 a.m.‡ | 52 | 88 | — | — | 52.0 |
| Sept. 12 | 9 a.m.§ | 58 | 76 | — | 18.0 | 15.0 |
| Sept. 12 | 2 p.m. | 76 | 30 | — | 9.5 | 9.0 |
| Sept. 12 | 6 p.m. | 59 | 76 | — | 9.0 | 10.0 |
| Sept. 13 | 8.30 a.m. | 61 | 74 | — | 15.0 | 14.0 |
| Sept. 13 | 11.30 a.m. | 65 | 67 | — | 12.0 | 12.0 |
| Sept. 13 | 2.30 p.m. | 72 | 50 | — | 10.0 | 12.0 |
| Sept. 13 | 5 p.m. | 71 | 57 | — | 10.0 | 9.4 |

*Harvested with 16-foot windrower September 4.
†Seven hours after light rain.
‡Twelve hours after rain of 0.5 inch, plants dripping wet.
§Thirty-six hours after rain of 0.5 inch.
**From small stack harvested on September 6 with a "header-barge."

By the afternoon of September 1 the moisture content of the seeds had been reduced to 8.7% compared with 19.2% in the threshed chaff of the bolls. A part of this difference in moisture content may be due to the nature of the materials compared, the oil-bearing seeds naturally holding less moisture than the fibrous bolls. It is probable,

however, that these mature but not dead plants were still conducting moisture from the soil to some extent, which would account for the higher moisture content of the boll tissues.

## MOISTURE CONTENT OF STANDING AND WINDROWED FLAX

It is a common practice to harvest flax with a header or special windrow harvester and leave it in the windrow for several days to dry. It is important to know whether the grain in the crop handled in this manner dries more rapidly than that in standing flax. Experiments bearing on this were made on the Fairway Farms, Brockton, Mont., in cooperation with M. L. Wilson. Samples were obtained at regular intervals from windrows of flax harvested on September 4 with a 16-foot International windrow-harvester, and from standing flax for comparison. The moisture content of the whole bolls was determined, rather than that of the threshed seed. The results are shown in Table 2.

On September 6, a hot day with low humidity, two days after harvesting, the flax in the windrow had a moisture content of 4.6 to 6.7%. It shows approximately the same moisture changes as the standing flax, the moisture content in both cases varying with the atmospheric humidity and from wetting by rain or heavy dew. It should be noted that the standing flax was nearly ripe, the bolls having a moisture content of 8.4% on September 6. In clean, mature flax, therefore, there does not appear to be any advantage in harvesting with the windrow-harvester, so far as reducing the moisture content is concerned. Where weeds are present, or in case it is desired to harvest before the crop is fully ripe, the windrower will make it possible to harvest before the crop is ready to harvest with the combine.

## MOISTURE CHANGES FOLLOWING RAIN, DEW, OR HIGH HUMIDITY

All observations indicate that the moisture content of the seeds in standing flax increases rapidly after light rain or heavy dew and is responsive also to changes in humidity. This can be seen by reference to any of the tables presented.

At Mandan (Table 1), on August 27, samples of flax seeds contained from 16 to 17% of moisture. The following morning, after a heavy dew, two samples taken at 7 and 9 a.m., respectively, contained 19.3 and 18.4% of moisture, respectively, in the threshed seeds. By 4 p.m. the moisture content had dropped to 14.5%. A rain of 0.1 inch at 10 p.m., on August 28, resulted in an increase of about 2% in moisture in the sample taken at 8 a. m. the next day. On September 1, a warm day of moderate humidity, the moisture content was lowered from 10.3% at 9 a.m. to 8.7% at 1 p.m.

TABLE 3.—*The moisture content of 71 samples of flaxseeds collected in successive two-hour periods during the day at Mandan, N. Dak., Brockton, Mont., and Jamestown, N. Dak., from August 27 to September 24, 1928, the samples of each group averaged being comparable.*

| Location, date, and condition of flax | Time of day 7–9:30 % | 9:31–11:30 % | 11:31–1:30 % | 1:31–3:30 % | 3:31–5:30 % | 5:31–7:30 % |
|---|---|---|---|---|---|---|
| | | | Mandan, N. Dak. | | | |
| Flax ripening | | | | | | |
| Aug. 27 | — | 15.9 | 17.0 | 16.3 | — | — |
| Aug. 28 | 19.3 | 17.9 | 16.7 | — | 14.5 | 14.5 |
| | 18.4 | — | — | — | — | — |
| Aug. 29 | 16.6 | — | — | — | — | — |
| Average | 18.1 | 16.9 | 16.9 | 16.3 | 14.5 | 14.5 |
| Aug. 31 | | — | — | — | — | 9.0 |
| Sept. 1 | 10.3 | — | 8.7 | — | — | 8.8 |
| | 10.3 | — | — | — | — | — |
| Sept. 2 | 9.2 | — | — | — | — | — |
| Average | 9.9 | — | 8.7 | — | — | 9.9 |
| | | | Brockton, Mont. | | | |
| Flax fully ripe | | | | | | |
| Sept. 4 | — | — | — | — | — | 9.0 |
| Sept. 5 | 8.0 | 8.0 | 7.0 | 6.8 | 8.0 | 7.0 |
| Sept. 6 | 8.9 | — | 8.0 | — | 6.0 | — |
| Sept. 9 | 9.0 | — | — | — | 8.8 | — |
| Average | 8.6 | 8.0 | 7.5 | 6.8 | 7.6 | 8.0 |
| Sept. 12* | 15.0 | — | — | 9.0 | — | 10.0 |
| Sept. 13* | 14.0 | 12.0 | — | 12.0 | 9.4 | — |
| Average | 14.5 | 12.0 | — | 10.5 | 9.4 | 10.0 |
| | | | Jamestown, N. Dak. | | | |
| Flax fully ripe | — | 11.9 | 10.4 | 10.0 | 9.6 | 9.2 |
| Sept. 21 to 24 | — | 11.2 | 9.2 | 9.3 | 9.4 | 9.1 |
| From combine | — | 11.0 | 9.8 | — | 9.0 | 9.2 |
| Recleaned seed | — | 10.4 | — | — | 9.0 | — |
| | — | 9.6 | — | — | 8.7 | — |
| Average | — | 10.8 | 9.8 | 9.7 | 9.1 | 9.2 |
| Standing flax | 9.3 | 9.3 | 9.1 | 8.0 | 8.3 | 9.1 |
| Hand threshed | 9.4 | 8.4 | — | 8.0 | 8.0 | 8.4 |
| | 10.2 | 8.3 | — | 7.6 | 8.0 | 9.0 |
| | — | 8.4 | — | 8.2 | — | — |
| Average | 9.6 | 8.6 | 9.1 | 8.0 | 8.1 | 8.8 |

*After rain of 0.5 inch on the evening of September 10.

At Brockton, Mont., (Table 2) the samples of flax bolls taken from the windrow and from standing flax at intervals from September 6 to September 13 show a marked range in moisture content from day to day. On September 6, a warm day with low humidity, the moisture content of flax bolls from the windrow was reduced from 13.2% at 7 a.m. to 4.6% at 5 p.m. This was the lowest moisture content recorded during the period of sampling, and it was obtained only two days after the crop was harvested.

In the standing flax, the moisture content of the bolls was 8.0% at noon on September 6 and 8.3% on the morning of September 7. It increased to 13.2% at 8 a.m. on September 9, after 24 hours of higher humidity, and to 19.4% at 3 p.m. on September 10, about seven hours after a light rain. A heavy rain occurred on the evening of September 10. On September 12, the samples of bolls still contained 15.0% of moisture at 9 a.m., but were dry enough to thresh at 2 p.m. when the moisture content had fallen to 9.0%.

TABLE 4.—*The moisture content and weight per bushel of flaxseed threshed from standing flax at hourly intervals from 8 a. m. to 7 p. m. on Sept. 15, 1928, at the Northwest Substation, Crookston, Minn.**

| Hour | Temperature, °F | Relative humidity % | Test weight, pounds per bushel | Moisture % |
|---|---|---|---|---|
| 8:00 | 58 | 94 | 43.0 | 31.5 |
| 9:00 | 60 | 94 | 46.2 | 29.0 |
| 10:00 | 66 | 80 | 45.6 | 28.0 |
| 11:00 | 68 | 76 | 47.2 | 26.0 |
| 12 noon | 70 | 72 | 48.4 | 25.9 |
| 1:00 | 72 | 73 | —— | 24.0 |
| 2:00 | 73 | 69 | 48.8 | 23.9 |
| 3:00 | 74 | 65 | 52.4 | 18.4 |
| 4:00 | 73 | 61 | 52.2 | 17.8 |
| 5:00 | 71 | 60 | 53.4 | 15.8 |
| 6:00 | 67 | 75 | 52.6 | 16.2 |
| 7:00 | 63 | 89 | —— | 17.0 |

*The day was clear with slight breeze. The first sample was taken about 15 hours after a heavy rain, the last sample about 26 hours after the rain.

In Table 2 is shown also the moisture content of seeds threshed from standing flax at intervals from September 4 to 10 at Brockton, Mont. These samples ranged from 9.0% at 6 p.m. on September 4 to 6.0% at 5 p.m. on September 6, a hot, dry day. On September 9 the moisture content was again up to about 9.0%.

A summary of the moisture content in the seed samples collected at two-hour intervals during the day at Mandan and Jamestown, N. Dak., and Brockton, Mont., is presented in Table 3. These data

indicate that when the moisture content of the seeds is high there is likely to be a marked reduction in moisture during the day. This occurred at Mandan during the three days, August 27 to 29, and at Brockton on September 12 and 13. In both cases the samples collected in the afternoon contained from 3 to 4 % less moisture than the morning samples. On the other hand, when the seed contained less than 10% of moisture in the morning it usually lost only 1 or 2% during the day.

The rapid rate of drying on a clear day is shown by the moisture content of seeds from standing flax collected at hourly intervals on September 15, 1928, at the Northwest Substation, Crookston, Minn. The data are shown in Table 4. The moisture content of the seed decreased from 31.5% at 8 a.m. to 15.8% at 5 p.m., and then increased slightly to 17.0% at 7 p.m. The loss of moisture during the day amounted to fully 15%, although the flax was still too moist to harvest without further drying.

## MOISTURE CONTENT OF CLEAN FLAXSEED AND THAT INCLUDING DOCKAGE

During the four-day period, September 21 to 24, samples of flaxseed were obtained from a combine and from standing flax in a field of 130 acres near Jamestown, N. Dak. All of the samples were taken from one end of the field where the flax was comparatively uniform as to stand, ripeness, and number of weeds present. The weeds consisted chiefly of green foxtail, lamb's-quarters, and Amaranthus.

The moisture determinations are shown in Table 5. The samples from the combine, including the dockage, contained 10.7% of moisture on the average, as compared with 9.8% in the clean seed. The average moisture content of the standing flax, hand threshed from the field, was 8.6%.

The higher moisture content of the seed from the combine than from the standing flax indicates that the threshed seed took up moisture from the weed seeds and chaff present in the combine samples. A lapse of from two to four hours occurred between the time of taking the samples from the combine and the time of recleaning the seed and determining the moisture. During this period the threshed flaxseed absorbed approximately 0.8% of moisture from the greener weed seeds. The average moisture content of the weed seeds included in the dockage was 15.7%.

After flaxseed containing dockage is placed in storage, transference of moisture from the weed seeds to the flaxseed continues until there is equilibrium of moisture in the various contiguous seeds.

Ordinarily when the balance of moisture is reached, the dockage contains from 1 to 3% more moisture than the flaxseed.

TABLE 5.—*The percentage of moisture, bushel weight, and dockage in flaxseed harvested with combine, and percentage of moisture in standing flax threshed by hand during a four-day period, September 21 to 24, 1928, at Jamestown, N. Dak.*

| Day | Hour | Temperature, °F | Relative humidity % | Combined flax: Bushel weight, pounds | Combined flax: Dockage % | Combined flax: Moisture Including dockage % | Combined flax: Moisture Clean seed % | Hand threshed, moisture % |
|---|---|---|---|---|---|---|---|---|
| | | | | Field A | | | | |
| Sept. 21 | 10 a.m. | 56 | 50 | 53.6 | 20.2 | 12.8 | 11.9 | |
| | 11 a.m. | 60 | 44 | 54.2 | 14.0 | 12.0 | 11.2 | |
| | 12 m. | 62 | 36 | 53.2 | 12.0 | 11.4 | 10.4 | |
| | 2 p.m. | 66 | 32 | 53.4 | 14.5 | 11.2 | 10.0 | |
| | 4 p.m. | 66 | 32 | 53.6 | 13.6 | 11.0 | 9.6 | |
| | 5 p.m. | 64 | 50 | 53.6 | 13.3 | 10.0 | 9.4 | |
| | 5.30 p.m. | 62 | 54 | 53.7 | 12.8 | 9.8 | 9.0 | |
| | 6.40 p.m. | 60 | 63 | 53.2 | 16.7 | 10.6 | 9.2 | |
| Sept. 22 | 7.30 a.m. | 48 | 79 | | | | | 9.3 |
| | 8.30 a.m. | 48 | 79 | | | | | 9.4 |
| | 12 m. | 55 | 38 | 53.7 | 12.7 | 10.6 | 9.2 | 9.1 |
| Sept. 23 | 9 a.m. | 44 | 64 | | | | | 10.2 |
| | 10.30 a.m. | 49 | 42 | 53.8 | 18.0 | 12.2 | 11.0 | 9.3 |
| | 2.30 p.m. | 53 | 50 | | | | | 8.0 |
| | 3.30 p.m. | 51 | 50 | 52.8 | 17.0 | 10.2 | 9.3 | 8.0 |
| | 4.30 p.m. | 50 | 48 | 52.4 | 13.8 | 9.6 | 9.0 | 8.3 |
| | 5.15 p.m. | 45 | 57 | 52.4 | 14.6 | 9.4 | 8.7 | 8.0 |
| | 6.15 p.m. | 44 | 60 | 52.6 | 17.8 | 10.0 | 9.1 | 9.1 |
| Sept. 24 | 9.45 a.m. | 40 | 45 | 51.7 | 17.1 | 11.6 | 10.4 | |
| | | | | Field B | | | | |
| Sept. 23 | 11 a.m. | 49 | 42 | | | | | 8.4 |
| | 2 p.m. | 54 | 42 | | | | | 9.6 |
| | 3 p.m. | 53 | 50 | | | | | 8.2 |
| | 5 p.m. | 49 | 42 | | | | | 8.0 |
| | 6 p.m. | 45 | 47 | | | | | 8.4 |
| | 7.30 p.m. | 40 | 81 | | | | | 9.0 |
| Sept. 24 | 9.45 a.m. | 40 | 45 | | | | | 8.3 |
| | 10.50 a.m. | 44 | 43 | 51.8 | 14.3 | 10.2 | 9.6 | 8.4 |
| | 12 m. | 47 | 34 | 51.7 | 15.4 | 10.4 | 9.8 | |
| | 5.40 p.m. | 45 | 78 | 52.1 | 14.9 | 9.8 | 9.2 | |
| Average of all samples | | | | 53.3 | 15.2 | 10.7 | 9.8 | 8.6 |

## EFFECT OF DELAYED HARVEST ON YIELD, BUSHEL WEIGHT, AND MOISTURE CONTENT

At University Farm, St. Paul, Minn., replicated square-yard plats of two varieties of flax, Redwing and Buda, were pulled on eight dates during August, 1928. The yield per acre, bushel weight, and moisture content of the seeds and straw were determined for the first five dates and some data obtained on the other three. The data for the Redwing variety are shown in Table 6. The moisture content of the seeds decreased from 20% on August 6 to 11.8% on August 14, a decrease of 8.2% in eight days. The seeds of Buda decreased in moisture from 23.8% on August 8 to 11.8% on August 14, a decrease of 12% in six days. The moisture content of both varieties increased to about 19% on August 20, following a heavy rain.

There was no significant difference in the yield per acre of the Redwing variety from the five dates of harvesting on which this information was obtained. The test weight increased as the moisture decreased. The seed tested 46.1 pounds per bushel on August 4 and 52.5 pounds on August 20.

TABLE 6.—*The acre yields, bushel weights, and moisture content of seeds and straw of Redwing flax harvested on eight dates, from August 4 to 24, 1928, at University Farm, St. Paul, Minn.**

| Date of harvest | | Yield per acre, bushels | Weight per bushel, pounds | Moisture content of Seed % | Moisture content of Straw % |
|---|---|---|---|---|---|
| August | 4 | 25.3 | 46.1 | 20.0 | 64.1 |
| | 6† | 23.3 | 46.6 | 20.0 | 62.7 |
| | 8 | 24.6 | 46.2 | 21.2 | 61.8 |
| | 10 | 25.6 | 49.8 | 18.2 | 59.8 |
| | 12 | 24.5 | 49.0 | 18.8 | 63.7 |
| | 14 | — | — | 11.8 | — |
| | 20‡ | — | 52.5 | 19.0 | — |
| | 24§ | — | 52.0 | 15.3 | — |

*Plants 25 inches high, lodged somewhat. Flax bolls ripe (brown) on August 4, straw partly green until August 24.

†Rain of 1.44 inches between August 4 and 6.

‡Rain of 1.62 inches between August 14 and 20.

§Rain of 0.72 inch between August 20 and 24.

At the Waseca Substation, about 60 miles south of St. Paul, six varieties of flax were harvested on each of five dates from August 6 to September 8, 1928, and the acre yields and bushel weights determined (Table 7). The average yield of the six varieties was 18.2 bushels per acre on August 11, 18.1 bushels on August 17, 17.5 bushels on August 24, and 17.7 bushels on September 8. There apparently was a loss in yield of about 0.5 bushel per acre between

the first two dates (August 11 and 17) and the last two dates (August 24 and September 8). The higher yield of the four varieties harvested on August 6 may have been due to a higher moisture content. There was little variation in the average bushel weight of the seed from the five dates of harvest.

At the West-Central Substation, Morris, Minn., two varieties, Redwing and Linota, were harvested on four dates, August 21 and 24, September 18, and October 1, 1928, and the acre yields, bushel weight, and moisture content of the seed determined. The results are shown in Table 8.

It is apparent from the data presented that no decrease in yield per acre occurred from the later dates of harvest. The increase shown on October 1 probably is due to sampling. It should be noted that there was no lodging of the crop up to the last date of harvesting, although it stood for five or six weeks after ripening. The test weight ranged from 53.2 to 56.0 pounds per bushel, and varied inversely with the moisture content of the seed.

TABLE 7.—*Acre yields and bushel weights of six varieties of flax harvested on five dates, August 6 to September 8, 1928, at the Southeast Substation, Waseca, Minn.*

| Variety | August 6 | August 11 | August 17 | August 24 | Sept. 8 | Yield per acre, bushels: Average of four dates Aug. 11 to Sept. 8 | Average weight per bushel, pounds |
|---|---|---|---|---|---|---|---|
| Linota | 22.1 | 19.3 | 20.2 | 19.1 | 20.3 | 19.7 | 52.7 |
| Redwing | 20.9 | 17.8 | 18.4 | 17.2 | 17.5 | 17.7 | 53.1 |
| Rio (Long 79) | —— | 19.6 | 18.3 | 17.6 | 18.5 | 18.5 | 49.7 |
| Winona | 19.2 | 16.0 | 16.3 | 16.7 | 15.7 | 16.2 | 53.9 |
| Buda | —— | 17.6 | 18.2 | 17.1 | 17.6 | 17.6 | 53.3 |
| Bison | 19.1 | 19.0 | 17.1 | 17.2 | 16.4 | 17.4 | 50.7 |
| Av. yield per acre | 20.3 | 18.2 | 18.1 | 17.5 | 17.7 | —— | —— |
| Av. weight per bushel | 52.9 | 52.4 | 52.3 | 52.1 | 52.2 | —— | —— |

TABLE 8.—*Acre yield, bushel weight, and moisture content of seed of two varieties of flax, Redwing and Linota, harvested on four dates, from August 21 to October 1, 1928, at the West-Central Substation, Morris, Minn.*

| Date of harvest | Redwing: Yield per acre, bushels* | Redwing: Bushel weight, pounds | Redwing: Moisture % | Linota: Yield per acre, bushels* | Linota: Bushel weight, pounds | Linota: Moisture % |
|---|---|---|---|---|---|---|
| August 21 | 20.3 | 54.0 | 11.2 | 19.8 | 54.0 | 9.8 |
| August 24 | 21.0 | 55.7 | 9.0 | 22.1 | 55.7 | 9.0 |
| September 18† | 20.1 | 53.2 | 12.1 | 22.4 | 53.2 | 11.7 |
| October 1 | 24.1 | 56.0 | 6.5 | 24.9 | 55.2 | 6.7 |
| Average | 21.4 | | | 22.3 | | |

*Calculated on basis of 9% of moisture.

†Rainfall of 2.14 inches from August 24 to September 18.

The moisture content of flaxseed of the Linota variety was determined on six dates in a period of eight days between August 13 and 20 at the North Dakota Agricultural Experiment Station, Fargo, N. Dak. The acre yield was also determined on August 24, when the crop was ripe, and on three later dates. These data are shown in Table 9.

The moisture content ranged from 9.2% on August 14 to 17.0% on August 16, a day of high humidity. The acre yield decreased from August 24, when the crop was first ripe enough to harvest with a binder, to September 21, four weeks later. This loss may be attributed to excessively heavy rains which occurred after the crop was ripe.

TABLE 9.—*The moisture content of flax bolls and the bushel weight and acre yield of seed of Linota flax harvested at intervals from August 3 to September 21, 1928, at Fargo, N. Dak.*

| Date | | Relative humidity % | Moisture content Bolls % | Moisture content Seed % | Bushel weight, pounds | Yield per acre, bushels |
|---|---|---|---|---|---|---|
| August | 3 | 46 | 60.5 | | | |
| | 4 | 50 | 56.6 | | | |
| | 6 | 69 | 53.4 | | | |
| | 7 | 35 | 48.6 | 29.7 | | |
| | 8 | 42 | 46.2 | 28.5 | | |
| | 9 | 38 | 37.5 | | | |
| | 10 | 30 | 40.1 | | | |
| | 11 | 43 | 33.1 | | | |
| | 13* | 52 | 16.4 | 11.1 | | |
| | 14 | 48 | 12.7 | 9.2 | | |
| | 15 | 70 | | 12.2 | 51.2 | |
| | 16 | 90 | | 17.0 | | |
| | 17† | 42 | | 12.6 | 53.0 | |
| | 20 | 57 | | 11.6 | 54.0 | |
| | 24‡ | | | | 57.0 | 19.8 |
| Sept. | 3§ | | | | 56.0 | 18.5 |
| | 10 | | | | 55.5 | 17.5 |
| | 21** | | | | 54.0 | 13.8 |

*Half of bolls brown.
†Crop ripening slowly.
‡Crop fully ripe.
§Rain of 4.3 inches from August 25 to 31.
**Rain of 2.2 inches from September 11 to 20.

## THE MOISTURE LIMIT FOR SAFE STORAGE

Most of the flaxseed produced in the United States is inspected and graded under Minnesota grading rules which permit a maximum moisture content of 11% in flaxseed graded as No. 1 and No.

2. The test is made on the basis of the clean flax after removal of dockage.

It is probable that clean flaxseed containing not over 11% of moisture is safe for storage in cool weather. The Grain Division of the Federal Bureau of Agricultural Economics found that car lots of flaxseed containing from 10.1 to 10.5% of moisture sometimes spoil in transit in warm weather, and that damage more frequently occurs when the flaxseed contains more than 10.5% of moisture.

Flaxseed containing from 10 to 11% of moisture may be considered safe for storage under average conditions. It is not safe, however, when exposed to high humidity or high temperature.

In some years hundreds of cars of flaxseed too wet for safe storage are shipped to market. This occurred during the fall of 1926 when continued wet weather prevailed throughout much of the flaxseed-producing area, preventing the proper drying of flax after harvest. In Table 10 is shown the moisture content of flaxseed of the 1926 and 1927 crops received at the Minneapolis market. In 1926 nearly 53% of the receipts (3,322 cars) contained from 10.1 to 12% of moisture, as compared with 8.2% (769 cars) in 1927.

TABLE 10.—*Range of moisture content in flaxseed of the 1926 and 1927 crops as determined by carlot receipts at the Minneapolis market.**

| Moisture % | 1926 crop† | | 1927 crop‡ | |
|---|---|---|---|---|
| | Number of cars | Percentage of total number | Number of cars | Percentage of total number |
| 5.1 to 6.0 | 0 | 0.0 | 57 | 0.6 |
| 6.1 to 7.0 | 23 | 0.4 | 759 | 8.1 |
| 7.1 to 8.0 | 263 | 4.2 | 2,696 | 28.7 |
| 8.1 to 9.0 | 764 | 12.1 | 3,265 | 34.7 |
| 9.1 to 10.0 | 1,572 | 25.0 | 1,811 | 19.3 |
| 10.1 to 11.0 | 2,217 | 35.3 | 636 | 6.8 |
| 11.1 to 12.0 | 1,105 | 17.6 | 133 | 1.4 |
| 12.1 to 13.0 | 275 | 4.4 | 33 | 0.4 |
| 13.1 to 14.0 | 50 | 0.8 | 8 | 0.1 |
| 14.1 to 15.0 | 11 | 0.2 | 2 | 0.0 |
| 15.1 to 18.0 | 6 | 0.1 | 2 | 0.0 |
| 18.1 to 21.0 | 3 | 0.0 | 1 | 0.0 |
| Average | 6,289 | | 9,403 | |

*Moisture tests made by the Minnesota State Inspection Department.
†Cars received from October 15, 1926, to August 31, 1927, inclusive.
‡From September 1, 1927, to August 31, 1928.

In 1926, 23% of the receipts contained over 11% of moisture. Such flaxseed was not safe for storage, but fortunately it could be worked by the linseed mills before the hot weather of summer came on.

It is evident that flaxseed which varies greatly in moisture content also has a considerable range in value. Flaxseed is a high-priced product, and the relative values of different lots of seed depend upon the quantity of oil and linseed cake or meal which they will produce. Northwestern flaxseed of good quality and containing not over 8% of moisture will yield in crushing about 19 pounds of linseed oil and 37 pounds of linseed cake or meal per bushel (56 pounds) of seed. As the percentage of moisture increases the yield of oil and of cake decreases as the excess moisture is lost in the process of extraction of the oil. If the cost of dry seed (8% moisture content) is $2.24 per bushel, the value of seed of higher moisture contents, and the approximate yield of oil and of meal per bushel of flaxseed, would be as follows:

| Moisture % | Value per bushel | Yield of products per bushel: Oil, pounds | Meal, pounds |
|---|---|---|---|
| 8 | $2.24 | 19.0 | 37.0 |
| 10 | 2.20 | 18.6 | 36.3 |
| 12 | 2.15 | 18.2 | 35.5 |
| 14 | 2.11 | 17.9 | 34.8 |
| 16 | 2.06 | 17.5 | 34.0 |
| 18 | 2.02 | 17.1 | 33.3 |

In the manufacture of linseed oil, the flaxseed is finely ground, then conducted to a large steam-jacketed metal drum or "heater" where it is heated with steam to about 98° C before it is conducted to the presses to extract the oil. Flaxseed containing 8 or 9% of moisture is preferred as this allows the addition of live steam which facilitates the extraction of the oil. Wet flaxseed is objectionable, not only because of its lower yield of oil and linseed cake, but because of the difficulty of grinding and pressing. It sticks to the rolls in grinding and squeezes out of the press cloths in pressing. Wet flaxseed must be dried in the heating process before extracting the oil.

# DEHISCENCE OF THE FLAX BOLL[1]

A. C. DILLMAN[2]

In a study of flax varieties for the purpose of classification, the writer has observed that three major types of flax bolls can be distinguished readily according to the nature of their dehiscence. In the first type, *Linum usitatissimum crepitans* Boningh, the bolls are completely dehiscent, the segments separating widely and scattering the seeds as soon as the boll is ripe. In the second type, which includes practically all varieties grown commonly for seed or fiber in the United States, the bolls are semi-dehiscent when the plants are ripe, i.e., the boll opens at the apex and the five segments separate slightly along their margins. It is rarely, however, that the bolls of this type dehisce so far as to allow the seeds to fall out. In the third type, represented by most of the Argentine strains, the boll remains tightly closed when ripe. These three principal types of bolls are shown in Fig. 1, drawn by R. C. Steadman.

In the common varieties of flax the ripe bolls are highly hygroscopic, the bolls opening as they dry out but closing tightly again when wet by dew or rain (Fig. 1, B and B′). The writer believes that this character can be used as an indicator of the proper condition of flax for harvesting, particularly with the combine.

During the ripening process of the flax plant, the following changes can be observed: (1) At first a few of the early bolls near the base of the panicle begin to dehisce; (2) in a few days the majority of the bolls dehisce; and (3) finally the remainder of the bolls dehisce, the whole plant turns brown, the leaves shrivel, and the stems become dry. In some cases it is advantageous to harvest with the binder or windrower when the flax is only partly ripe, at the stage described under 2, and allow the harvested crop to dry in the shock or windrow. For combining, the crop should be fully ripe, as indicated by the condition described under 3.

In moisture determinations of ripening flax made at Mandan, N. Dak., in 1928, only a very few bolls began to dehisce when the seeds contained as much as 14 to 19% of moisture. Nearly all bolls were semi-dehiscent when the seed contained approximately only 9% of moisture. The exact moisture content at which partial dehiscence occurs has not been determined. It probably occurs when the seeds contain from 9 to 11% of moisture.

[1]Contribution from Office of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture, Washington, D. C. Received for publication March 8, 1929.

[2]Associate Agronomist in Charge of Flax Investigations.

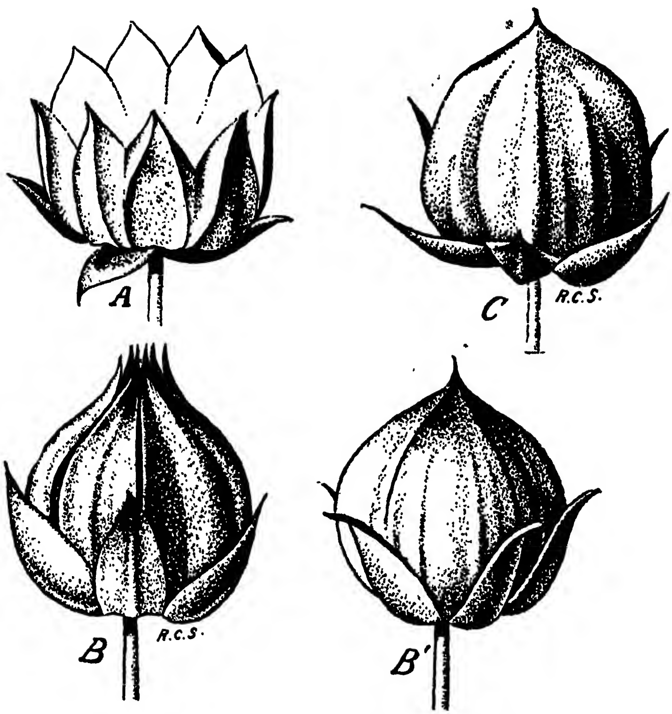


FIG. 1.—Principal types of flax bolls. A, the dehiscent boll of *Linum usitatissimum crepitans* Boningh; B, boll of common flax in which the bolls are semi-dehiscent when ripe and dry; B′, the same boll as in B when wet by rain or dew; and C, boll of Argentine type which is indehiscent even when fully ripe and dry. X 4.

In flax dry enough to thresh readily with the combine the bolls are partly open (semi-dehiscent). This was the condition of the flax in a score or more of fields observed by the writer during the fall of 1928, where combines were working most efficiently. When the flax is tough, as in the morning after dew, or after a trace of rain, the bolls are closed. As the flax dries out the bolls open at the apex and along the margins of the segments.

This discussion does not apply to the Argentine type of flax in which the bolls ordinarily remain tightly closed when fully ripe.

# THE SOIL REACTION PROFILE[1]

E. A. NORTON AND R. H. BRAY[2]

During the past few years increasing attention has been given to study of the observable features of the component parts of the soil profile. The texture, structure, color, consistence, and other observable features of each horizon are carefully studied and recorded in an effort to characterize, recognize, and differentiate soil types. The chemical composition and reaction, particularly of the surface horizon, of the soil profile have long been recognized as important soil characteristics, but they have not been commonly used in differentiating soils except in establishing broad categorical schemes of classification (1)[3]. It appears that, until appropriate field methods are developed, chemical analysis must continue to be used as a means of characterizing separations already made, and of testing their validity. Reaction determinations, however, as will be brought out in this paper, appear to offer an additional tool which may be used by the field man in helping to solve difficult problems.

The study of the reaction soil profile reported in this paper was made in Illinois on some established soil types to determine whether the reaction of horizons in the profiles of these types was significantly different, and whether it could be correlated with observable characteristics. It was thought that if such proved to be the case, the reaction profile could be used to help differentiate soils in the field. Similar studies have been made by others (10, 11, 12), but no definite conclusions can be drawn from the work reported because of limitations in the samples available for study, or for other reasons noted by the authors.

## PROCEDURE

The potentiometric method, with the hydrogen electrode, was selected as the most satisfactory single test to indicate the reaction. This method determines the intensity of acidity or basicity and the results are closely associated with the degree of saturation of the acid colloid (2). This relationship is of particular importance in this work because the degree of saturation may be a criterion of degree of weathering in the soils studied. Samples were taken from

[1]Contribution from the Agronomy Department, Illinois Agricultural Experiment Station, Urbana, Ill. Published with the approval of the Director. Received for publication March 8, 1929.

[2]Assistant Chief in Soil Survey Mapping and First Assistant in Soil Survey Analysis, respectively.

[3]Reference by number is to "Literature Cited," p. 844.

fresh cuts or excavations in areas the profiles of which were first examined to determine if they were typical of the types which it was desired to study. Virgin profiles were selected wherever possible, the samples being taken in virgin forests, undisturbed roadside sods, and sod border strips along experiment field plats. It is unlikely that many of the profiles had ever been cultivated; and those few which might have been were not cultivated long enough to have been materially changed. The material in the transition zones was collected with the horizon which it most nearly resembled. Each sample thus included a portion throughout the entire thickness of the horizon and adjacent transition zones if present. The sampling was done in the late summer and early fall of 1927 and 1928. During both of these periods the moisture content was below optimum for cultivation. The samples were placed in cloth bags and immediately brought to the laboratory where they were prepared by air drying and screening through a 20-mesh sieve. The hydrogen-ion concentration was determined with the hydrogen electrode within a few months of the date of sampling. This treatment and storage are thought to have had little or no effect on the reaction (3).

## SOILS STUDIED

The soil types studied, designated by the Illinois name and number and, when possible, by the U. S. Bureau of Chemistry and Soils name, together with the counties in which the samples were taken, and the number of samples, are listed by groups in Table 1.

In the presentation of the results of this study, the soils are placed in four groups, as shown in Table 1. Group 1 includes four mature soils, Group 2 three Slick Spot soils, Group 3 four immature soils, and Group 4 three youthful soils.

A full description of the soils in Group 1 may be found in an earlier number of this JOURNAL (4). These soils are considered to be mature because they have reached a stage of relative equilibrium with their environment, as evidenced by their strongly developed and clearly defined horizons, indicating that future changes under the same environment will be slow and of little consequence (6). All the samples in this group were taken from virgin profiles in forested areas. These soils were developed under an average annual rainfall of 41.5 inches, a mean temperature of 55° F, and an average growing season of 188 days.

The Slick Spot soils have been divided into three types, the division being based on the depth from the surface at which the compact, plastic, columnar clay occurs. Slick Spots have developed in

TABLE 1.—*Groups of soils studied.*

| Type name | Type No. | Location of samples, county | Number of samples In county | Total |
|---|---|---|---|---|
| | | Group 1—Mature Soils | | |
| Light Gray Silt Loam On Tight Clay | 11 | Wayne | 1 | 11 |
| (Formerly Marion silt loam) | | Macoupin | 4 | |
| | | Effingham | 3 | |
| | | Fayette | 3 | |
| Yellow-Gray Silt Loam On Tight Clay | 12 | Randolph | 1 | 11 |
| (Vigo silt loam) | | Wayne | 1 | |
| | | Macoupin | 5 | |
| | | Effingham | 4 | |
| Yellow-Gray Silt Loam On Compact Medium-Plastic Clay | 13 | Randolph | 1 | 11 |
| (Gibson silt loam) | | Wayne | 1 | |
| (Tilsit silt loam) | | Effingham | 5 | |
| | | Fayette | 4 | |
| Reddish Yellow-Gray Silt Loam | 14 | Effingham | 1 | 10 |
| (Princeton silt loam) | | Wayne | 2 | |
| | | Jefferson | 1 | |
| | | Jackson | 2 | |
| | | Monroe | 1 | |
| | | Randolph | 1 | |
| | | Jersey | 2 | |
| | | Group 2—"Slick Spot" Soils—Mature | | |
| Slick Spot A | 120A | Macoupin | 7 | 13 |
| | | Effingham | 4 | |
| | | Fayette | 2 | |
| Slick Spot B | 120B | Macoupin | 4 | 10 |
| | | Effingham | 3 | |
| | | Fayette | 3 | |
| Slick Spot C | 120C | Macoupin | 1 | 11 |
| | | Effingham | 1 | |
| | | Wayne | 6 | |
| | | Fayette | 3 | |
| | | Group 3—Immature Soils | | |
| Brown Silt Loam On Clay | 43 | Fulton | 7 | 12 |
| (Grundy silt loam) | | McDonough | 2 | |
| | | Macoupin | 3 | |
| Light Brown Silt Loam | 36 | Henry | 3 | 11 |
| (Tama silt loam) | | Ogle | 7 | |
| | | Woodford | 1 | |

TABLE 1—*Continued.*

| Type name | Type No. | Location of samples, county | Number of samples In county | Total |
|---|---|---|---|---|
| | | Group 3—Immature Soils—*Continued* | | |
| Brown Silt Loam (Muscatine silt loam from Peorian loess area) | 41b | Fulton | 7 | 22 |
| | | Macoupin | 6 | |
| | | Henry | 9 | |
| Brown Silt Loam (Muscatine silt loam from Wisconsin drift area) | 41a | Piatt | 5 | 15 |
| | | Champaign | 10 | |
| | | Group 4—Youthful Soils | | |
| Brown Silt Loam On Calcareous Drift (Clarion silt loam) | 59 | Will | 7 | 7 |
| Brown Silt Loam On Plastic Calcareous Drift (Webster silt loam) | 67 | Will | 6 | 6 |
| Black Clay Loam On Drab Clay (Loessial Clyde clay loam) | 66 | Piatt | 5 | 5 |

southern Illinois chiefly in association with Types Nos. 11 and 12, and in southwestern Illinois in association with types related to Nos. 11 and 12 but having darker colored surface soils (4). Slick Spots are thought to be mature soil types in equilibrium with their present environment, even though they have a secondary base accumulation within some horizon of their profile, which is contrary to the prevalent belief that the bases freed by the weathering of a soil material in a humid temperate climate are carried away by the process of leaching. These soils are found only in a region where a relatively shallow calcareous loess has been deposited on a mature, poorly drained, therefore highly impervious, drift-derived soil (5). This slightly pervious buried soil has interrupted the drainage and leaching of the overlying calcareous material, resulting in accumulation of the products of weathering as secondary minerals. The secondary accumulation includes unusually high amounts of replaceable sodium and calcium (13), and calcium carbonate is found precipitated in some of the horizons in the upper, or superimposed profile. The B horizon in Slick Spot profiles is a very compact clay which is arranged in columns that are thinly coated with a light-colored material. These columns offer much resistance to wetting when dry, but when wet are highly plastic, absorb water readily, and offer little resistance to penetration.

The above is but a brief statement of present views regarding the origin of Slick Spots and may be modified or completely changed with further study. The zone of accumulation in the A type of Slick Spot occurs within 10 inches of the surface. This type supports little or no vegetation. The zone of accumulation in the B type occurs between 10 and 20 inches. Crop growth is seriously affected on this type. The zone of accumulation in the C type occurs below 20 inches. Crop growth in this type is affected only in years of unfavorable climatic conditions.

The soils of Group 3 occur extensively in central-western and northwestern Illinois. They are developing under a grass vegetation and are considered to be immature because many and relatively rapid changes will take place in their profile characteristics before they can be said to be in equilibrium with their present environment. A fairly complete description of the characteristics of the soils in this group and the environment under which they have developed may be found in Illinois Soil Report No. 36 (7). The samples of the types in this group were taken largely from roadside sod, as virgin fields do not exist.

The soils of Group 4 occur extensively in north-central and northeastern Illinois in the Wisconsin drift area. The soils of this group are considered to be youthful because their horizons are imperfectly developed, leaching has not progressed far, and therefore they will change rapidly under their present environment. A fairly complete statement of the profile features of these soils and the environment under which they are developing may be found in Illinois Soil Report No. 36 (7). As was the case with the soils of Group 3, the samples of these types were taken from roadside sod.

## RESULTS AND DISCUSSION

The hydrogen-ion concentration of each horizon to a depth of about 42 inches of the 13 soil types listed in Table 1 was determined. The averages only are given, together with their probable errors calculated by Peter's formula. The number of samples in each average ranges from 5 to 22, with but one made up of only 5 individuals and most of them consisting of 11 or 12. The results for the soils in Group 1 are shown in tabular form in Table 2.

The reaction of the lower horizons in the mature soil types listed in Table 2 indicates that a pH of about 4.8 is the lowest which occurs in the soils of this region under their present environment. There is no statistical difference between the pH of the lower horizons in any of these types, irrespective of their wide variation in physical, chemical, and biological condition, as observed and measured in the field.

TABLE 2.—*Results of the study of Group 1—mature soils.*

| Type No. | Horizon | Limits in inches | pH | Type No. | Horizon | Limits in inches | pH |
|---|---|---|---|---|---|---|---|
| | $A_1$ | 0– 4 | 5.03±0.05 | | $A_1$ | 0– 6 | 5.76±0.09 |
| | $A_2$ | 4–14 | 4.82±0.04 | | $A_2$ | 6–14 | 5.26±0.05 |
| | $A_3$ | 14–22 | 4.85±0.05 | | $A_3$ | 14–18 | 5.01±0.06 |
| 11 | $B_1$ | 22–30 | 4.92±0.04 | 13 | $B_1$ | 18–22 | 4.88±0.03 |
| | $B_2$ | 30–38 | 4.92±0.06 | | $B_2$ | 22–28 | 4.84±0.04 |
| | $B_3$ | 38–42 | 4.94±0.04 | | $B_3$* | 28–38 | 4.82±0.04 |
| | | | | | $B_4$ | 38–42 | 4.94±0.06 |
| | $A_1$ | 0– 6 | 5.01±0.07 | | $A_1$ | 0– 6 | 5.62±0.07 |
| | $A_2$ | 6–12 | 4.90±0.06 | | $A_2$ | 6–12 | 5.03±0.07 |
| 12 | $A_3$ | 12–18 | 5.05±0.05 | 14 | $B_1$ | 12–18 | 4.74±0.03 |
| | $B_1$ | 18–28 | 5.05±0.05 | | $B_2$ | 18–26 | 4.77±0.04 |
| | $B_2$ | 28–36 | 5.17±0.09 | | $B_3$ | 26–34 | 4.89±0.06 |
| | $B_3$ | 36–42 | 5.18±0.12 | | $B_4$ | 34–42 | 4.96±0.04 |

*Separation of the B from the C horizon in the soil profiles reported in this paper was made considering the B to be a zone of advanced chemical decomposition, a lithologic, structural, and reaction unit within which illuviation has occurred, and which may or may not have textural uniformity (5), instead of the designation suggested by Shaw (6) that the B horizon is the horizon of deposition to which materials have been added by percolating waters, the illuviated horizon of the solum.

The pH of the surface horizon of Types Nos. 13 and 14 is significantly higher than that of Types Nos. 11 and 12. This difference may be due to the ability of the former types to support a greater vegetative growth than the latter. Observation in the field indicates this to be true. Table 2 shows that the thickness of the surface horizon in Types Nos. 13 and 14 is greater than that of Type No. 11. The total organic-carbon content, as reported in Illinois Soil Report No. 34 (14), is twice as much in the former two as in the latter. Further discussion of this point is taken up following Table 5.

Table 3 gives the results for the soils in Group 2.

TABLE 3.—*Results of the study of Group 2—Slick Spot soils.*

| Type No. | Horizon | Limits in inches | pH | Type No. | Horizon | Limits in inches | pH |
|---|---|---|---|---|---|---|---|
| | A | 0– 8 | 6.07±0.16 | | $A_1$ | 0– 8 | 4.95±0.05 |
| | $B_1$ | 8–14 | 7.87±0.12 | | $A_2$ | 8–14 | 5.36±0.07 |
| 120A | $B_2$ | 14–20 | 8.50±0.05 | 120C | $A_3$ | 14–18 | 5.62±0.08 |
| | $B_3$ | 20–34 | 8.90±0.04 | | $B_1$ | 18–24 | 5.96±0.08 |
| | $B_4$ | 34–42 | 8.70±0.06 | | $B_2$ | 24–30 | 6.24±0.08 |
| | | | | | $B_3$ | 30–36 | 7.48±0.17 |
| | $A_1$ | 0– 8 | 5.28±0.09 | | $B_4$ | 36–42 | 8.41±0.06 |
| | $A_2$ | 8–12 | 6.16±0.10 | | | | |
| 120B | $B_1$ | 12–18 | 6.78±0.14 | | | | |
| | $B_2$ | 18–26 | 7.96±0.16 | | | | |
| | $B_3$ | 26–32 | 8.71±0.10 | | | | |
| | $B_4$ | 32–44 | 8.62±0.12 | | | | |

Table 3 shows clearly that the reaction of horizons in Slick Spots rises above a pH of 7.0 at the same place in the profile that a big change in physical characteristics takes place. The reaction in both the A and B types changes abruptly from acid to alkaline near the point at which the friable, structureless, silty material changes to a compact, plastic, columnar clay. It was noted in the field that the subhorizons $B_3$ and $B_4$ were less compact and plastic than $B_1$ or $B_2$. Table 3 shows that the reaction of the subhorizons $B_3$ and $B_4$ rises above a pH of 8.5. There must be some property present in these horizons which influences both the pH and the physical characteristics. Bray (13) points out that the $B_2$ horizon of four Slick Spot profiles analyzed contained extremely high amounts of replaceable sodium. This fact suggests that the presence of an excess of replaceable sodium may have increased the pH and changed the physical character of these horizons.

Table 4 gives the results for the soils in Group 3.

TABLE 4.—*Results of the study of Group 3—immature soils.*

| Type No. | Horizon | Limits in inches | pH | Type No. | Horizon | Limits in inches | pH |
|---|---|---|---|---|---|---|---|
| | $A_1$ | 0–8 | 6.06±0.10 | | $A_1$ | 0–8 | 5.90±.038 |
| | $A_2$ | 8–14 | 6.26±0.08 | | $A_2$ | 8–16 | 6.14±.051 |
| 43 | $A_3$ | 14–18 | 6.20±0.11 | 41a | $A_3$ | 16–20 | 6.35±.052 |
| | $B_1$ | 18–26 | 6.29±0.13 | | $B_1$ | 20–28 | 6.68±.053 |
| | $B_2$ | 26–34 | 6.63±0.13 | | $B_2$ | 28–36 | 7.08±.059 |
| | $B_3$ | 34–42 | 7.02±0.12 | | $B_3$ | 36–42 | 7.35±.072 |
| | $A_1$ | 0–8 | 5.73±0.06 | | $A_1$ | 0–8 | 5.81±.060 |
| | $A_2$ | 8–14 | 5.56±0.05 | | $A_2$ | 8–14 | 5.85±.041 |
| 36 | $B_1$ | 14–26 | 5.54±0.05 | 41b | $A_3$ | 14–20 | 5.90±.029 |
| | $B_2$ | 26–30 | 5.63±0.05 | | $B_1$ | 20–28 | 6.08±.042 |
| | $B_3$ | 30–40 | 5.96±0.08 | | $B_2$ | 28–32 | 6.18±.047 |
| | | | | | $B_3$ | 32–42 | 6.77±.064 |

The pH of the horizons in the profiles of three immature soil types developed under prairie vegetation in central, western, and northwestern Illinois is shown in Table 4. These types have a large areal distribution over the above-mentioned region. The pH determinations indicate considerable difference in the degree of decomposition and leaching between corresponding horizons of these immature profiles. Type No. 36, developed on rolling topography under good drainage, has a distinctly acidic reaction profile as indicated by a pH considerably below 6.0, while Type No. 43, developed on flat topography under poor drainage, has a reaction profile near neutrality, as indicated by a pH of considerably above 6.0. The pH of

the horizons in the profiles of Types Nos. 41a and 41b, which occupy intermediate topographic and drainage positions, lies between that of Types Nos. 36 and 43. The pH of the horizons of the mature soils (Group 1, Table 2) does not indicate any difference between corresponding horizons in the rate of decomposition and leaching as measured by the hydrogen-ion concentration. However, certain physical characteristics of these mature profiles indicate that a definite difference exists. Further study now in progress may bear out the tentative conclusion that there are differences in the rate of decomposition and leaching correlated with differences in topography and drainage (5).

Very definite differences in the amount of leaching as measured by the pH of the horizons is observed in a comparison of the profiles of Type Nos. 41a and 41b. The younger profile, developed from a loess accumulation of post-Wisconsin age, has a significantly higher pH in all but the $A_1$ horizon than the older profile, developed from the Peorian loess. This difference can well be accounted for by the difference in the length of time which has elapsed since each was exposed to weathering. These two profiles have much the same physical characteristics, yet are noticeably different in depth of leaching and in response to crops and fertilizer treatment. Both have been subject to similar environment, but one, No. 41b, is derived from loess of Iowan age, having been exposed to weathering for a longer period than the other, 41a, developed from the recent loess accumulated on top of the Wisconsin drift (8). The significance of the differences in the pH of the horizons of these two profiles was calculated by the following formulae (9):

$$\frac{\text{difference in means}}{\pm\sqrt{(E_1)^2 + (E_2)^2}} = Z^4 \text{ and } \frac{2 \times \frac{1}{2}(1-a)}{\frac{1}{2}(1+a) - \frac{1}{2}(1-a)} = \text{odds}^5.$$

The odds that the difference in pH 0.09 in the $A_1$ horizon is significant are 1.4:15. The odds that the difference in pH 0.29 in the $A_2$ horizon is significant are 332 : 1. The odds that the difference in pH 0.45 in the $A_3$ horizon is significant are more than a million to 1. The odds that the difference in pH 0.60 in the $B_1$ horizon is significant are more than a trillion to 1. The odds that the difference in pH 0.90 in the $B_2$ horizon is significant are overwhelming. The odds that the difference in pH 0.58 in the $B_3$ horizon is significant are more than 100,000 to 1.

Table 5 gives the results for the soils in Group 4.

[4]The correction for the use of Peter's formula for calculating probable error would not affect the result in this case.

[5]Odds of 100: 1 considered significant.

TABLE 5.—*Results of the study of Group 4—youthful soils.*

| Type No. | Horizon | Limits in inches | pH | Type No. | Horizon | Limits in inches | pH |
|---|---|---|---|---|---|---|---|
| | $A_1$ | 0– 8 | 6.53±0.10 | | $A_1$ | 0– 8 | 5.72±0.07 |
| | $A_2$ | 8–16 | 6.98±0.08 | | $A_2$ | 8–12 | 5.95±0.14 |
| 66 | $A_3$ | 16–20 | 7.17±0.10 | 59 | $A_3$ | 12–16 | 6.20±0.16 |
| | $B_1$ | 20–30 | 7.50±0.08 | | $B_1$ | 16–24 | 7.39±0.20 |
| | $B_2$ | 30–36 | 7.60±0.09 | | $B_2$ | 24–30 | 7.77±0.14 |
| | C | 36–44 | 7.67±0.06 | | D† | 30–42 | 8.24±0.02 |
| | $A_1$ | 0– 8 | 6.11±0.17 | | | | |
| | $A_2$ | 8–14 | 6.44±0.15 | | | | |
| 67 | $A_3$ | 14–20 | 6.99±0.12 | | | | |
| | B | 20–32 | 7.64±0.10 | | | | |
| | D* | 32–40 | 8.06±0.07 | | | | |

*The C horizon was very shallow and was not separated from D.
†The D horizon is designated as the oxidized but unleached zone (15).

The view that the soils in Group 4 are youthful is apparently substantiated by the pH horizons of these profiles as given in Table 5. The horizons in these profiles are not well developed and it is difficult to separate them in the field. Few, if any, characteristics which are the result of soil development can be observed below the B horizon in these profiles. Differences in pH in the A horizon of these types are probably due to differences in drainage and amounts of vegetative growth supported.

The changes made in the soil material as a result of the action of the forces of weathering should be more pronounced on the surface and decrease with depth. The surface horizon of a soil profile developed from a calcareous deposit, as all of the soil types reported in this paper have been, should be more acidic than any other part of the profile. The reaction as indicated by the pH of horizon $A_1$ of Types Nos. 13, 14, 36, 41a, 41b, and 59 makes it appear that this is not the case, but that early in the process of soil formation a pH of about 5.7 is reached which might be termed an equilibrium point between the accumulation of bases through organic growth and decay and the loss of bases through leaching (10). This equilibrium position seems to be maintained as long as the necessary plant-food elements become available for the soil to support a good vegetative growth. When a vigorous vegetation can no longer be supported, the pH falls considerably below 5.7. Types Nos. 11 and 12 do not support a good vegetation and the pH of their surface horizon is about 5.0. Types Nos. 43, 66, and 67 support a very luxuriant vegetation and have probably not reached this equilibrium point pH 5.7. It should be noted that the youthful profile of Type No. 59

has a pH of about 5.7 in the surface horizon. It appears that a productive soil in this region has been able to maintain a pH of at least 5.7 in the $A_1$ horizon of its virgin profile.

The results of the hydrogen-ion concentration of soil horizons reported in this paper indicate that the reaction profile is a relatively stable soil-type character. They show that horizons can be differentiated by means of pH determinations in many soil profiles, and that the profile of one type is significantly different from that of others. A measure of the length and intensity of weathering in different profiles is indicated by the respective pH of the horizons. The reaction profile is, therefore, a part of the general character of a soil, and it appears to offer possibilities of application to the problems of separation, correlation, and mapping of soils.

## SUMMARY

Early in the process of soil formation, the pH of the $A_1$ horizon of the soils in Illinois becomes 5.7, which seems to be a position of equilibrium between the accumulation of bases from the decay of organic matter and the loss of bases by leaching. This pH is maintained as long as the soil is able to support a good vegetative growth. It appears that a soil in this region which is productive must have been able to maintain a surface pH of at least 5.7 in the virgin profile.

The highest acidity which might be expected in the mature soils of this region under present environment is a pH of about 4.8.

Differences in the rate of leaching were observed in immature soils. Soils developed on rolling well-drained topography were more acid throughout the profile than those developed on flat topography under poorly drained conditions.

A significant difference was observed in the amount of leaching in two profiles of the same soil type differing only in the length of time they had been subjected to weathering.

The pH of the Slick Spot profiles shows a good correlation with the texture, structure, and consistence characteristics as observed in the field and with replaceable sodium as determined in the laboratory.

The above points lead to the conclusion that the reaction profile is a relatively stable soil character, and that it can be considered as an aid to the separation of soil types.

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# INCREASING THE PROTEIN CONTENT OF PASTURE GRASSES BY FREQUENT LIGHT APPLICATIONS OF NITROGEN[1]

C. R. Enlow and J. M. Coleman[2]

There are many instances cited in literature of increasing protein content of various crops by applying nitrogenous fertilizers (1, 2, 3, 4, 13).[3] There are other instances of increased protein in grasses from association with legumes (5, 6) and from the growing of crops on soils high in nitrate (7, 12). In many cases the protein content of pasture flora has been increased by top-dressings of fertilizers, containing phosphate, lime, or potash (8, 9), mainly by the increased cover of various legumes. On much of the cut-over land of Florida, however, and in particular the higher sandy lands, pasture legumes do not flourish, even when these elements are supplied. Protein content has also been increased by frequent mowing of pasture grasses (14). The value of frequent top dressings of nitrogenous fertilizers for increasing the carrying capacity of pasture grasses has been shown (10).

It has been demonstrated at the Florida Experiment Station and on many farms throughout the state that certain improved pasture grasses make excellent growth throughout a considerable portion of the year. Grasses grown on soils with a low nitrogen content, however, generally contain low percentages of nitrogen, as can be noted from analyses given below. Any increase in protein content which may be made by fertilizing pasture grasses should make a better balanced feed, requiring less high-priced protein supplements for grazing dairy cows and fattening beef cattle. Preliminary work in 1927 indicated that grass top-dressed with sulfate of ammonia not only produced a much greater amount of forage when mowed frequently than when not treated with the nitrogen fertilizer, but the clippings contained a higher percentage of total nitrogen.

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[3]Reference by number is to "Literature Cited," p. 853.

The 1928 experiments were planned to determine, if possible, whether light applications of a nitrogen fertilizer alone on pasture grasses under pasture conditions would give increased protein content (as indicated by the 1927 experiments), using the total nitrogen content as the indicator of protein content, and also give increased forage production, when mowed often enough to simulate grazing by livestock. Bahia grass (*Paspalum notatum*), carpet grass (*Axonopus compressus*), and centipede grass (*Eremochloa ophiuroides*) were used for the experiment. These are three of the most promising grasses for cut-over pine lands, bahia and centipede in particular being well adapted to dry soils. All three grasses spread by creeping stolons, making their best spread when grazed or mowed. Yields and nitrogen content of bahia and centipede grasses are shown in Table 1.

TABLE 1.—*Yields in pounds per acre and percentage of total nitrogen of bahia and centipede grasses grown on Norfolk sand, Gainesville, Florida, 1927.*

| | | Mowed eight times | | | Mowed only at end of season | | |
|---|---|---|---|---|---|---|---|
| Grass | Treatment | Green weight, pounds | Oven-dry weight, pounds | Total nitrogen* % | Green weight, pounds | Oven-dry weight, pounds | Total nitrogen % |
| Bahia | Nitrogen; watered† | 14,933 | 4,744 | 2.10 | 22,620 | 8,686 | 1.07 |
| Bahia | No treatment | 5,934 | 2,073 | 1.71 | 2,575 | 1,648 | 0.84 |
| Centipede | Nitrogen; watered† | 6,860 | 2,798 | 1.93 | 12,528 | 5,460 | 1.17 |
| Centipede | No treatment | 2,372 | 876 | 1.32 | 870 | 526 | 0.77 |

*Average of last seven mowings, as by mistake no samples were saved from the first mowing for nitrogen determinations.

†Nitrogen as sulfate of ammonia and nitrate of soda.

It will be noted from Table 1 that the percentage of total nitrogen is lowest where the grass received no treatment and was cut only at the end of the season. The forage yields in this instance are also very low, the late summer of 1927 being exceptionally dry (Table 6). On the plats which were fertilized, applications of nitrogenous fertilizers alone were made once each month at the rate of 140 pounds of nitrogen per acre per year in the inorganic form. This was started in 1926. The nitrogen applications are made throughout the year. Water is applied as needed by overhead irrigation. This accounts for the large increase of forage over those plats not fertilized and watered. The percentage of total nitrogen is much higher where grasses were fertilized and watered but not mowed until the end of the growing season than where they were not fertilized or watered and were not mowed. This shows the possibility of increasing the nitrogen content of hay.

Where the plats were mowed frequently, the samples from the plats fertilized and watered ran consistently higher in total nitrogen content than the samples from the check plats. The average of the nitrogen determinations made are given in Table 2 by date of mowing.

TABLE 2.—*Percentage of total nitrogen in dried samples of grass from frequent mowings, 1927.*

| Grass | Treatment | Percentage of total nitrogen by date of mowing | | | |
|---|---|---|---|---|---|
| | | July 18 | Aug. 4 | Aug. 22 | Sept. 1 |
| Bahia | Nitrogen and water | 2.22 | 1.78 | 2.10 | 2.04 |
| Bahia | No treatment | 1.75 | 1.73 | 1.71 | 1.70 |
| Centipede | Nitrogen and water | 2.13 | 1.77 | 2.26 | 1.57 |
| Centipede | No treatment | 1.40 | 1.30 | 1.25 | 1.35 |
| | | Sept. 28 | Oct. 13 | Nov. 21 | |
| Bahia | Nitrogen and water | 1.85 | 2.38 | 2.31 | |
| Bahia | No treatmsnt | 1.73 | 1.67 | 1.71 | |
| Centipede | Nitrogen and water | 1.77 | 1.97 | 2.01 | |
| Centipede | No treatment | 1.30 | 1.34 | 1.32 | |

In view of the results obtained in 1927, experiments were started in 1928 to determine the feasibility of making light applications of nitrogen to pasture grasses and thereby increasing the yield of forage per acre and at the same time increasing the nitrogen content of the grass. Several hundred plats of various grasses were planted on the Experiment Station grounds and in the pastures from 1922 to 1926 in order to determine the best time of planting pasture grasses. Some of these plats are on deep Norfolk sand, others on Norfolk sand, gravelly phase, and still others on low-lying Portsmouth soil. Several plats of carpet, bahia, and centipede grass were chosen for the work on the Norfolk soils, while carpet grass alone was used on the Portsmouth soil. No fertilizers had been applied to any of the plats previous to starting this experiment. Top dressings of sulfate of ammonia were applied to plats of all three grasses at the rate of 16.66 pounds of nitrogen per acre the first of April, May, and June, totaling 50 pounds of nitrogen per acre per year. Other plats were not fertilized. A total of nine mowings were made on the Norfolk plats and eight on the Portsmouth. The plats on the Portsmouth soil were under water a short time late in August, making it necessary to delay mowing several days.

A summary of the 1928 results are given in Table 3 and the percentage of total nitrogen by date of cutting in Table 4. Table 4 shows very pronounced increases in the nitrogen content of all the grasses top dressed with sulfate of ammonia for the first four

cuttings as compared with the checks on all three soils, with the exception of the carpet grass on the Norfolk sand, gravelly phase. The fertilized carpet plats on this soil gave greater increases in forage over the checks than any other plats in the experiment, but for some reason the nitrogen content was variable.

TABLE 3.—*Effect of sulfate of ammonia on the yield and protein content of pasture grasses grown on different soil types, Florida Experiment Station, 1928.*

| Grass and treatment | Green weight per acre, pounds | Oven-dry weight per acre, pounds | Average percentage nitrogen in dry material | Pounds nitrogen per acre in grass cut | Percentage of nitrogen recovered in grass |
|---|---|---|---|---|---|
| | | High Norfolk Sand | | | |
| Bahia, fertilized | 9,290 | 2,778 | 1.618 | 43.38 | 32.1 |
| Bahia, not fertilized | 5,187 | 1,809 | 1.540 | 27.32 | |
| Centipede, fertilized | 3,655 | 1,387 | 1.424 | 19.23 | 22.3 |
| Centipede, not fertilized | 1,686 | 711 | 1.270 | 8.10 | |
| Carpet, fertilized | 6,054 | 1,759 | 1.740 | 28.66 | 29.1 |
| Carpet, not fertilized | 3,238 | 999 | 1.543 | 14.11 | |
| | | Norfolk Sand, Gravelly Phase | | | |
| Bahia, fertilized | 9,297 | 2,779 | 1.619 | 43.28 | 33.4 |
| Bahia, not fertilized | 6,321 | 1,817 | 1.491 | 26.58 | |
| Centipede, fertilized | 7,465 | 2,117 | 1.613 | 34.83 | 36.3 |
| Centipede, not fertilized | 4,489 | 1,162 | 1.442 | 16.69 | |
| Carpet, fertilized | 12,206 | 3,060 | 1.675 | 50.47 | 48.3 |
| Carpet, not fertilized | 6,811 | 1,613 | 1.667 | 26.33 | |
| | | Portsmouth Soil Low Land | | | |
| Carpet, fertilized | 14,255 | 3,801 | 1.602 | 59.00 | 32.3 |
| Carpet, not fertilized | 11,945 | 2,995 | 1.471 | 42.86 | |

The last application of sulfate of ammonia was made June 7, immediately after the second cutting. At this time the percentage of total nitrogen was high in both fertilized and check samples, but a pronounced drop can be noted in both during July, August, and September, at which time the rainfall and grass yields were high. (See Fig. 1.) Also, the percentage of total nitrogen in the samples from the fertilized plats decreases more rapidly than those of the check samples, but they do not meet until the very light cutting of November 15 when rainfall was very low.

Although the increases noted in total nitrogen content practically disappear late in the season, such is not the case with the forage increases. The yields in pounds of oven-dry grass per acre by date of cutting are given in Table 5.

TABLE 4.—*Percentage of total nitrogen in grass mowings, 1928.*

| Grass and treatment | Percentage of total nitrogen by date of mowing | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Norfolk Sand** | | | | | | | | |
| | May 9 | June 7 | June 29 | July 16 | Aug. 11 | Aug. 30 | Sept. 21 | Oct. 11 | Nov. 15 |
| Bahia, sulfate of ammonia | 1.69 | 1.92 | 1.70 | 1.45 | 1.37 | 1.44 | 1.59 | 1.77 | 1.63 |
| Bahia, check | 1.30 | 1.66 | 1.55 | 1.53 | 1.51 | 1.55 | 1.58 | 1.59 | 1.59 |
| Centipede, sulfate of ammonia | 1.39 | 1.50 | 1.65 | 1.32 | 1.30 | 1.28 | 1.12 | 1.22 | 2.04 |
| Centipede, check | 1.03 | 1.12 | 1.18 | 1.25 | 1.24 | 1.18 | 1.22 | 1.22 | 1.99 |
| Carpet, sulfate of ammonia | 1.69 | 1.97 | 2.19 | 1.49 | 1.34 | 1.54 | 1.35 | 1.43 | 2.66 |
| Carpet, check | 1.20 | 1.61 | 1.66 | 1.43 | 1.42 | 1.27 | 1.31 | 1.42 | 2.57 |
| | **Norfolk Sand, Gravelly Phase** | | | | | | | | |
| | May 9 | June 7 | June 28 | July 17 | Aug. 8 | Aug. 30 | Sept. 19 | Oct. 11 | Nov. 15 |
| Bahia, sulfate of ammonia | 1.88 | 2.02 | 1.74 | 1.43 | 1.53 | 1.35 | 1.59 | 1.49 | 1.54 |
| Bahia, check | 1.34 | 1.86 | 1.61 | 1.37 | 1.42 | 1.33 | 1.50 | 1.41 | 1.58 |
| Centipede, sulfate of ammonia | 1.96 | 2.10 | 1.88 | 1.68 | 1.74 | 1.46 | 1.41 | 1.12 | 1.17 |
| Centipede, check | 1.68 | 1.75 | 1.55 | 1.37 | 1.50 | 1.33 | 1.31 | 1.17 | 1.32 |
| Carpet, sulfate of ammonia | 1.75 | 2.01 | 1.97 | 1.56 | 1.65 | 1.51 | 1.49 | 1.54 | 1.60 |
| Carpet, check | 1.70 | 2.12 | 1.71 | 1.60 | 1.59 | 1.55 | 1.58 | 1.53 | 1.62 |
| | **Portsmouth Soil** | | | | | | | | |
| | May 9 | June 7 | June 28 | July 17 | Aug. 8 | Sept. 19 | Oct. 11 | Nov. 15 | |
| Carpet, sulfate of ammonia | 1.58 | 1.89 | 1.88 | 1.44 | 1.64 | 1.20 | 1.51 | 1.68 | |
| Carpet, check | 1.39 | 1.63 | 1.64 | 1.34 | 1.48 | 1.24 | 1.42 | 1.63 | |

TABLE 5.—*Pounds of oven-dry grass per acre, 1928 mowings.*

| Grass and treatment | Pounds dry weight by date of mowing | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Norfolk Sand | | | | | | | | |
| | May 9 | June 7 | June 29 | July 16 | August 11 | August 31 | Sept. 21 | Oct. 11 | Nov. 15 |
| Bahia, sulfate of ammonia | 291 | 261 | 475 | 512 | 490 | 274 | 282 | 146 | 47 |
| Bahia, check | 328 | 89 | 246 | 286 | 238 | 183 | 256 | 142 | 41 |
| Centipede, sulfate of ammonia | 290 | 107 | 221 | 148 | 223 | 141 | 155 | 64 | 38 |
| Centipede, check | 296 | 71 | 100 | 75 | 48 | 44 | 49 | 17 | 11 |
| Carpet, sulfate of ammonia | 267 | 113 | 226 | 290 | 322 | 189 | 187 | 121 | 44 |
| Carpet, check | 210 | 56 | 104 | 112 | 210 | 105 | 110 | 66 | 26 |
| | Norfolk Sand, Gravelly Phase | | | | | | | | |
| | May 9 | June 7 | June 28 | July 17 | August 8 | August 31 | Sept. 19 | Oct. 11 | Nov. 15 |
| Bahia, sulfate of ammonia | 66 | 158 | 404 | 445 | 721 | 415 | 292 | 202 | 76 |
| Bahia, check | 92 | 112 | 227 | 248 | 337 | 294 | 280 | 162 | 65 |
| Centipede, sulfate of ammonia | 100 | 155 | 336 | 207 | 477 | 385 | 261 | 151 | 45 |
| Centipede, check | 83 | 103 | 154 | 95 | 190 | 253 | 169 | 94 | 21 |
| Carpet, sulfate of ammonia | 124 | 123 | 393 | 349 | 911 | 507 | 332 | 212 | 109 |
| Carpet, check | 103 | 104 | 180 | 167 | 274 | 291 | 217 | 179 | 98 |
| | Portsmouth Medium Sand | | | | | | | | |
| | May 9 | June 7 | June 28 | July 17 | August 8 | Sept. 19 | Oct. 11 | Nov. 15 | |
| Carpet, sulfate of ammonia | 188 | 275 | 806 | 557 | 640 | 901 | 259 | 175 | |
| Carpet, check | 205 | 166 | 572 | 423 | 454 | 804 | 230 | 141 | |

TABLE 6.—*Rainfall in inches by months; Gainesville, Fla.**

| | Jan. | Feb. | Mar. | Apr. | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ave. | 3.31 | 2.87 | 3.21 | 2.21 | 3.11 | 6.57 | 7.32 | 6 .76 | 5.65 | 2.84 | 2.04 | 3.22 | 49.11 |
| 1927 | 0.19 | 5.78 | 2.33 | 0.46 | 0.46 | 10.31 | 5.46 | 5.48 | 1.02 | 2.33 | 1.03 | 1.84 | 36.01 |
| 1928 | 1.26 | 2.73 | 2.91 | 4.50 | 4.50 | 7.64 | 9.23 | 11.91 | 9.34 | 1.41 | 0.22 | 1.03 | 60.70 |

*Data from Mitchell and Ensign (11).

As previously mentioned, the yields of grass ran consistently higher in the fertilized plats all season as can be seen in Table 5. The effects of the high summer rainfall on growth can be noted by the higher yields obtained from the third to the seventh cutting (June 29 to September 21). It might be of interest here to give the average rainfall by months at Gainesville, and also the actual rainfall during 1927 and 1928 (Table 6).

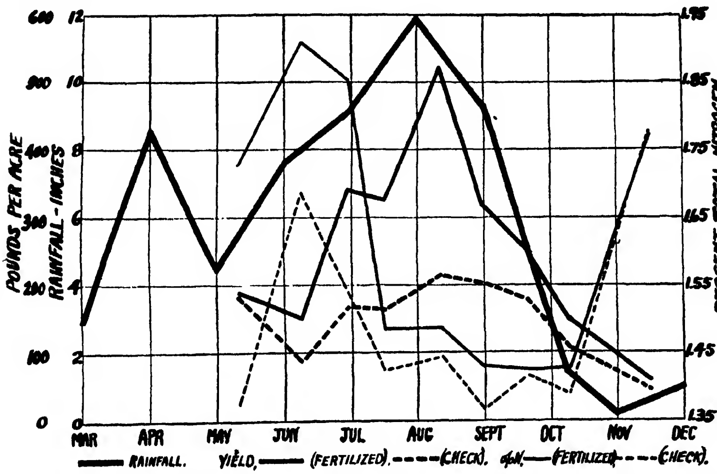


FIG. 1.—Relation of rainfall to yields of pasture grasses by mowings and the percentage of total nitrogen in the mowed samples.

The heavy line represents the 1928 rainfall by months from March to December. The medium width solid line represents the yield per acre of dry grass from the fertilized plats by date of mowing and the medium width dotted line shows the same for the check plats. The narrow solid line represents the percentage total nitrogen in samples from the fertilized plat mowings and the narrow dotted line the same for the check plats.

It will be noted from Table 6 that the spring and late summer of 1927 were very dry, while the 1928 rainfall was abnormally heavy to October. Also, the distribution during 1928 was much better than in 1927. Frequent rains are necessary during the summer on the higher sandy soils to prevent drouth conditions.

From a study of the tables, several interesting points can be noted. Apparently, there is a fairly close correlation between rainfall and yield of grass, both in the fertilized and unfertilized plats, although much more pronounced in the former. The behavior of the total nitrogen content of the grass also makes it appear that rainfall is the limiting factor as there is an inverse correlation between the rainfall and total nitrogen content or between yield and total nitrogen con-

tent. The number of pounds of dry grass produced per pound of nitrogen is less following periods of low rainfall as can be noted in Table 7.

TABLE 7.—*Pounds of oven-dry material produced per pound of nitrogen at various dates of cutting, average of all samples.*

| Treatment | Pounds of dry matter per pound of total N by date of cutting | | | |
|---|---|---|---|---|
| | May 9 | June 7 | June 29 | July 16 |
| Sulfate of ammonia | 56.9 | 52.1 | 53.9 | 67.2 |
| No treatment | 72.7 | 59.3 | 64.8 | 69.2 |
| | Aug. 31 | Sept. 2 | Oct 11 | Nov. 15 |
| Sulface of Ammonia | 69.9 | 70.2 | 70.0 | 56.4 |
| No treatment | 73.1 | 70.6 | 71.9 | 56.2 |

A comparison of the yields per pound of total nitrogen shown in the no-treatment plats with the rainfall of the preceding month shows that the high April rainfall gave a high figure, 72.7 pounds, in the May 9 cutting, while the lesser rainfall of May gave 59.3 pounds of dry material per pound of nitrogen. This relationship holds throughout the season. Where nitrogen was supplied by sulfate of ammonia, the pounds of dry matter per pound of nitrogen remained fairly low and constant. Seemingly, the grass naturally contained more total nitrogen if it was available in the soil.

In order to show graphically the relationship between rainfall, forage yield, and total nitrogen content, the chart in Fig. 1 was constructed. The averages of all the grass yields and total nitrogen content were used in constructing the chart. The rainfall represents monthly precipitation for 1928.

It is quite evident that the yield follows the rainfall, and more so when nitrogen is supplied. Also, it can be noted that the total nitrogen content is higher in the grass when plentiful in the soil, and is also high at periods of low rainfall, due to the small quantity of forage produced.

## CONCLUSIONS

The protein content of the grasses mowed frequently averaged much higher than when the grasses were cut only at the end of the growing season. This held true on both fertilized and unfertilized areas.

The protein content of pasture grass in a grazed condition can be increased and maintained at a somewhat higher level than ordinary by frequent light applications of a nitrogen fertilizer.

The pasture grasses used in this experiment gave much higher forage yields from the nitrogen applications as shown by yield records obtained and as indicated from results obtained in the pasture experiment.

Rainfall (rather than available soil nitrogen) is a limiting factor in forage production, as the ratio between the total nitrogen content of the grass and the pounds of forage produced is flexible.

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## WHY WE BELIEVE[1]

S. C. SALMON[2]

In these days of high pressure specialists in every field of endeavor as, for example, psychiatrists, dermatologists, pathologists, psychologists, plant breeders, statisticians—especially statisticians—etc., each of whom readily admits that the world regards his speciality altogether too lightly, it is refreshing, not to say unusual, to find a master who seems to have a wholesome regard for the limitations of his own subject. Such is Professor Edwin B. Wilson, if one may judge by the series of articles which have appeared in SCIENCE over his name during the past two years. His viewpoint is especially encouraging to those who believe that the development of modern statistical methods —wonderful though it has been—has not as yet made it unnecessary to use common sense and judgment in interpreting experimental results.

All of which is a prelude to the question, What constitutes proof or why we believe? Many writers apparently hold to the theory that every proposition must be submitted to statistical inquiry and that until this is done, any conclusions that may be reached have no validity whatever. Pearl (4, p. 18)[3], for example, says that "an experiment which takes no account of the probable error of the result reached is inadequate and as likely as not to lead to incorrect conclusions." Lipman and Linhart (2) concluded, as a result of applying statistical methods to the fertilizer experiments of the Pennsylvania and Ohio Agricultural Experiment Stations, perhaps the most useful of any in the United States, that "no fertilizer experiment as ordinarily conducted is possessed of sufficient practical value to justify the large expenditure of money, time, and energy involved."

Love (3) has cited with approval Gregoire's statement that "the large majority of the results of field experiments as ordinarily conducted are not only unworthy of serious consideration, but may be a veritable detriment to practical agriculture and discreditable to agronomic science," for no reason apparently other than that they have been conducted in such a way that statistical methods cannot be satisfactorily applied to their interpretation.

Harris (1, p. 251) infers that "experimental results without probable errors are of little significance."

Rietz (5) says that "a law of nature can be proved only in the sense of establishing a high degree of probability in its favor."

[1]Contribution No. 176, Dept. of Agronomy, Kansas Agricultural Experiment Station, Manhattan, Kan. Received for publication March 22, 1929.

[2]Professor of Farm Crops.

[3]Reference by number is to "Literature Cited," p. 859.

Thus it would appear that authoritative opinion favors the unqualified view that statistical proof is essential to sound, well-founded scientific belief. But is this necessarily the case? Does the statistical method always lead to truth? Does it always take into consideration all the facts necessary for the evaluation of observations, and is it not often possible to arrive at truth in other ways?

Pearl (4, p. 251) implies that our belief that the sun will rise in the morning is due to the fact that it has done so for one hundred million years with no exception, thus establishing a high degree of probability that it will continue to do so. Unfortunately, the illustration is defective in that we have no data of a statistical nature to prove that the sun has risen every morning for this period. Our belief that it has done so in the past and will continue to do so in the future is obviously founded on the known laws which govern the revolution of the earth on its axis and around the sun, the derivation of which can hardly be considered as due to the statistical method. The argument is therefore tautological and proves nothing so far as the question here under consideration is concerned.

The example does, however, illustrate the fact that belief in most phenomena depends on one or the other or both of two rather distinct groups of facts, *viz.*, (a) observations which may be submitted to statistical treatment and (b) knowledge of the principles and laws which govern the phenomena under consideration. The latter may or may not have been discovered as a result of the statistical method; in the past they generally have not been so discovered for the good reason that most of them antedate this method.

But regardless of its origin, it should be clear that the firmest and most dependable foundation for any scientific belief lies in an understanding of underlying principles and laws. Thus, our belief in tomorrow's sun depends not merely on observations of sunrise, but also on countless related phenomena, pertaining not only to the earth, but to all heavenly bodies. To question the sunrise is to predict a cosmic catastrophe. Likewise, it is our understanding of these laws that permits us to make allowance for apparent exceptions. Without it, we would like savages, be led into all sorts of fantastic beliefs at the first eclipse.

The question perhaps is of academic interest only, so far as it relates to the movements of the earth about the sun. It is quite otherwise as related to agricultural research. Consider, for example, the well-known effect of legumes on the nitrogen content of the soil and the yield of following crops. Statistical treatment of available data would probably supply good evidence of the beneficial effect

of legumes. But without our present knowledge of the symbiotic relation of bacteria and legumes, doubts would continually be engendered by the many exceptions that would occur as, for example, when no bacteria are present, when conditions are not favorable for the development of bacteria, or when, for other reasons, no gains in nitrogen or in yields are obtained, Like Darwin's contributions to the theory of evolution, our knowledge of the underlying phenomena makes the theory plausible, understandable, and convincing.

Pearl (4, p. 212), unwittingly, has given an excellent illustration of the fact that scientific belief is often based on understanding rather than on statistical probability. Wishing to impress upon his students

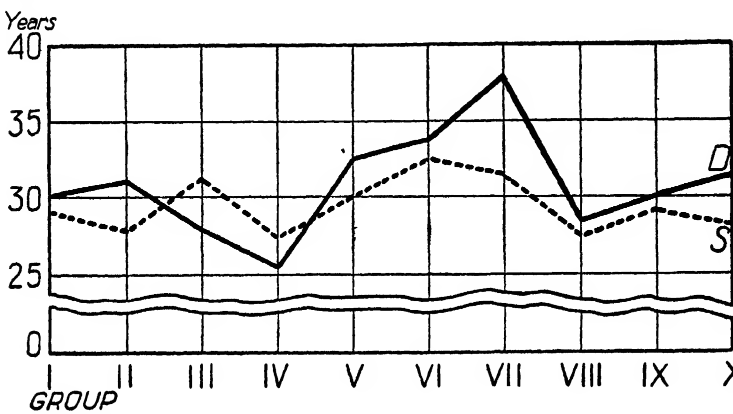


FIG. 1.—Mean age at marriage of two groups of persons selected at random from *Who's Who*. Each group is made up of ten sets of five each taken consecutively.

the necessity of statistical interpretation of experimental data, he calculated the age at marriage of ten groups of five persons each in *Who's Who* taken consecutively from a page chosen at random. A second calculation was made of a set of ten groups of five each from another page, also chosen at random. The two sets of data were graphed and are reproduced in Fig. 1.

The line marked D shows the average age at marriage of the first ten groups of five each, and the line S the second set of ten groups of five each. It will be observed that the average age at marriage for the two groups is different and that the trends of both lines are similar. Pearl points out that if an investigator had conducted an experiment and secured the results portrayed by the line D and had then, from a second experiment, secured the results given by the line S, he would have concluded that the second experiment confirmed the first. But, according to Pearl, this is wrong since the similarity

in the trends of the lines is entirely illusory. Unfortunately, he made no calculations to prove his point, since, if he had done so, he would have found a significant correlation between the two sets of data, and hence if our hypothetical investigator had done likewise, his erroneous belief that the second experiment verified the first would have been confirmed. Pearl evidently believes that there is no similarity in the trends of the two lines, not because statistical methods tell him so, but because there is no reason in the first place to expect such a relation.

As a matter of fact, conventional statistical proof of itself is seldom satisfactory. In the first place, the additional evidence which it supplies is negative. It shows not that an observed result is due to an assigned cause (as many seem to think), but merely that the observed result probably is or is not due to a definite, limited kind of error. So far as may be deduced from the statistical treatment, the result may have been due to other kinds of error or to any number of other causes which may or may not be known to the investigator.

In the second place, the laws of chance are often unsatisfactory as a basis for action or specific advice. Thus it can be statistically demonstrated as "practically certain" that one will not draw the ace, king, queen, jack, and ten of any given suit in a single hand at bridge. Nevertheless, there are few who would care to risk their lives or a large sum of money on the outcome. It would be much more satisfactory to know that all the tens or all the aces had been removed from the deck, thus eliminating all doubt.

Statistical analysis in many cases affords unsatisfactory proof for various reasons, among which may be mentioned (a) the fact that many experiments, especially field experiments in agriculture, do not furnish results which readily lend themselves to statistical manipulations because of bias, lack of randomness, or paucity of observations, and (b) most experiments afford evidence supplementary to the main issue which is of the greatest value in arriving at a reasonable interpretation of the results but which, for various reasons, is not readily included in a statistical analysis. Why then insist that statistical methods be applied to such cases when they serve only to cast doubt and disfavor on a result which otherwise is reasonably dependable and useful, or on the contrary, encourage a false sense of security?

The tacit assumption that experimental methods can never be such as to lead to certainty is also sometimes objectionable. It is much as though one were to insist that neither the aces nor the tens can be removed from the deck before drawing the hand at bridge; or that the only way to determine the proportion of colored marbles

in a bag is to draw a random sample and calculate the probable error when, as a matter of fact, the proportion could be more accurately and in some cases more easily determined by simply opening the bag and counting the marbles.

These arguments of course must not be pressed too far. Doubts cannot always be eliminated and no investigator, it is hoped, with so many contrary examples at hand, would maintain that plausibility constitutes proof. Yet may it not be admitted, regardless of what statistical interpretation of the data may show, that any proposition which is not plausible, i.e., is inconsistent with other known facts, is unlikely to be entirely correct, and conversely that a plausible hypothesis is worth considering until evidence is secured which renders it no longer plausible?

Generalizations are seldom entirely true, and certainly he is fearless who would seriously propose one relating to a subject, the designation of which implies the antithesis of standardization. Yet one is needed with respect to the prime objectives of research. Perhaps one with as few errors as any would affirm that the most important single objective of any experiment is to secure an understanding of the phenomena involved. With this understanding, it is easy to prove what is true; without it there is no proof, statistical or otherwise, that is convincing. Modern statistical methods, it is true, can often be used in securing this understanding, but it can often be obtained in simpler and equally effective ways. In such cases there is no need to insist on the employment of statistics.

The statistical method has suffered mostly from its friends. It has no enemies unless those who question certain statistical deductions when they clash with obvious facts can be considered as such. So many good things can be truthfully said of it that there really is no need for exaggeration. There is, on the other hand, a well-defined need for information and clear cut statements regarding the limitations and the assumptions, tacit and otherwise, that are involved when any statistical formula is applied to a specific set of observations. If more attention were given these things, the method would be misapplied less frequently, there would be less danger of it falling into disrepute, and there would be fewer experiments claimed to be of no value because not statistically interpreted.

Pasteur's admonition might well be more often observed in this connection. When certain extravagant claims for the new science of bacteriology were brought to his attention, he said, "I am the first to regret that inferences are drawn beyond the scope of the facts acquired. The exaggeration of new ideas invariably leads to reaction

which again overshooting the mark casts disfavor upon what is correct and fertile in those ideas. One ought to keep to the facts, study them afresh, and only deduce from them those ideas which, so to speak, can be regarded as justified."

Perhaps to avoid misunderstanding, it should be said that the writer is in full accord with those who see in modern statistical methods a useful means for supplementing the usual methods of interpreting experimental results; even to the extent of considering them essential to a full and complete interpretation in those cases in which the number of observations and conditions of the experiment completely justify their use.

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# NOTES

## A WASHING MACHINE FOR ROOT CROPS

Agronomists dealing with root crops are confronted with the problem of accurately determining and evaluating tare.[1] Irregularities in root shape and root type, as well as degree of branching, vary more or less with seasonal and soil differences, so that fixed percentage deductions to allow for soil adhering to roots are not trustworthy in calculating net yields of plats, unless roots are dug under optimum conditions when adhering soil falls off readily. Roots dug from wet soil give results that are questionable, unless unusual care is taken to remove all the soil from them. The fibrous roots found in the suture side of the sugar beet make it very difficult to remove all the soil with brushes.

FIG 1.—Rotating screen cylinder in washing position. Note handle with which clyinder is rotated or rocked.

FIG. 2—Rotating screen cylinder lowered to empty out sample. Note tin shield around cylinder. Also shutoff handle which controls water supply from front of machine.

Thorough washing of the roots obviously dispenses with the determination of a tare value, but does present the problem of how to wash a large number of samples quickly and thoroughly. The washing machine herein described and illustrated was built by the writers for

[1]In the sense here used, tare refers to a deduction that must be made from the gross yield of a plat because of the adhering soil.

use in the sugar beet breeding work carried on at the Michigan Experiment Station, and has been found to be efficient and satisfactory. This machine may be found of value to market gardeners, as it is adapted to washing all kinds of roots and vegetables for the market.

As will be noted in Figs. 1, 2, and 3, the washing machine which has been found satisfactory is essentially a screen wire cylinder which rotates around a stationary, horizontal axle. This axle is a ½-inch water pipe fitted with nozzles which are so arranged as to play their respective streams into the lower part of the screen cylinder. The nozzles found best suited for this work are the type used in over-

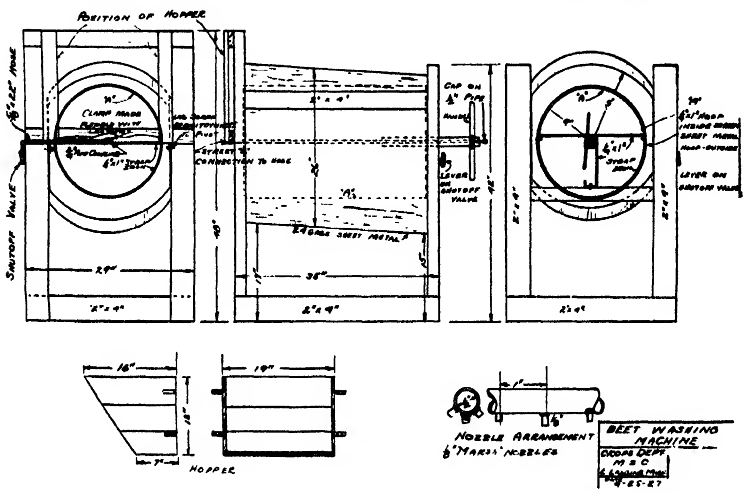

FIG. 3.—Detailed drawing and specifications of washing machine.

head irrigation systems, as they must throw a sharp fine stream rather than a spray or mist. This machine, the specifications for which are given in Fig. 3, is the size convenient to wash 10 to 15 sugar beets at one time, but can be made larger or smaller as needed.

When the cylinder is rotated or rocked the roots roll over and over in the bottom, while the streams of water from above strike them with considerable force, washing them clean in a very short time. In the case of beets, 15 roots can be washed free of soil particles in less than one minute. There is no breaking or injury to the roots whatever, making the machine ideal for cleaning selected mother beets and stecklings before putting in the storage cellar. When roots are clean, the operator shuts off the water, lowers the end of the cylinder (Fig. 2), and allows the roots to fall out into a metal basket which has a perforated bottom for free water to drain through quickly.

It is desirable to deliver the water to this machine at a reasonably high pressure to insure quick and efficient operation. The pressure of a city water supply will usually be adequate, but if more speed is desired a pressure pump may be used, such as is found on orchard sprayers. The writers use a motor-driven pump designated for wash-

TABLE 1.—*Comparison of methods of cleaning sugar beets.*

| Sample No. | Weight after knocking off dirt, pounds* | Weight after brushing off dirt, pounds† | Weight just after washing off dirt, pounds‡ | Weight of beets wiped dry after washing off dirt, pounds |
|---|---|---|---|---|
| 1 | 19.8 | 16.3 | 16.2 | 16.1 |
| 2 | 16.4 | 13.1 | 13.0 | 12.8 |
| 3 | 16.8 | 14.1 | 14.1 | 14.0 |
| 4 | 16.2 | 13.6 | 13.4 | 13.2 |
| 5 | 14.2 | 11.5 | 11.3 | 11.2 |
| 6 | 15.0 | 12.4 | 12.2 | 12.1 |
| 7 | 15.2 | 12.3 | 12.1 | 12.0 |
| 8 | 17.2 | 15.0 | 14.8 | 14.6 |
| 9 | 16.1 | 12.9 | 12.8 | 12.6 |
| 10 | 14.3 | 11.9 | 11.1 | 10.9 |
| 11 | 16.3 | 12.8 | 12.7 | 12.5 |
| 12 | 16.1 | 13.3 | 13.1 | 12.9 |
| 13 | 14.7 | 12.2 | 12.0 | 12.0 |
| 14 | 16.2 | 13.3 | 13.0 | 12.8 |
| 15 | 15.9 | 13.8 | 13.6 | 13.5 |
| 16 | 17.9 | 14.0 | 14.0 | 13.8 |
| 17 | 15.9 | 13.6 | 13.4 | 13.3 |
| 18 | 14.8 | 12.7 | 12.6 | 12.5 |
| 19 | 16.0 | 12.0 | 11.8 | 11.7 |
| 20 | 16.2 | 13.4 | 13.3 | 13.2 |
| 21 | 15.3 | 12.4 | 12.2 | 12.1 |
| 22 | 12.5 | 10.7 | 10.5 | 10.3 |
| 23 | 14.6 | 12.1 | 12.0 | 11.9 |
| 24 | 14.1 | 12.4 | 12.3 | 12.2 |
| 25 | 16.7 | 13.7 | 13.5 | 13.4 |
| Totals | 394.4 | 325.5 | 321.0 | 317.6 |
| Aver. wt. per sample | 15.78 | 13.02 | 12.84 | 12.71 |
| Aver. wt. per beet | 1.578 | 1.302 | 1.284 | 1.271 |

| | Per sample | Per beet |
|---|---|---|
| Average loss in weight by brushing, pounds | 2.76 | 0.276 |
| Average loss in weight by washing, pounds | 0.18 | 0.018 |
| Average loss in weight by wiping dry, pounds | 0.13 | 0.013 |

*Knocking off dirt required 1½ minutes per sample.

†Careful and thorough hand brushing required 4 to 5 minutes per sample.

‡Washing with machine required 1 minute or less per sample.

ing automobiles. This pump delivers 12 gallons of water to the machine per minute, at 300-pound pressure, giving the washer speed and efficiency. An auxiliary hose fitted with a spray gun is found useful in cleaning up beet washing and grinding apparatus and the work room at the end of each day.

The data given in Table 1 show the comparative efficiency and time required to clean root samples (1) by thorough hand brushing and (2) by machine washing. The beets of each sample were, first, knocked together to remove loose dirt; second, given a thorough hand brushing; third, washed clean in the machine; and fourth, wiped dry. Weighings were made between each step.

It will be noted from Table 1 that it is possible to brush the roots carefully enough so there is no significant difference in weight between a brushed sample and a sample which is washed clean, but the time required to brush off all soil particles is considerably greater than is required to wash them off.

The amount of free water adhering to the roots immediately after washing is negligible, as will be noted in Table 1, column 5, consequently samples can be weighed immediately as taken from the washing machine.—CHARLES A. LAVIS and GEORGE A. GETMAN, *Michigan State College of Agriculture, East Lansing, Mich.*

## A CEREAL NURSERY SEEDER

The seeder shown in Figs. 1 and 2 has proved very satisfactory for sowing a cereal nursery. The seeder consists of a fluted feed from an ordinary grain drill mounted on a garden seeder. The fluted feed is mounted on a hinged board which can be swung forward for cleaning purposes. A hopper is attached to the front part of the machine in which waste grain can be caught as the machine is cleaned. The feed is driven by a chain from the front wheel through a broken shaft, the detail of which is shown in Fig. 2. The rate of seeding is governed by adjusting the bolt and locknut on the left side of the feed. A device by which the rate of seeding could be changed more quickly and easily is desirable.

From 10 to 15 grams of seed are needed to fill the feed before any kernels are delivered in the furrow. A tin partition inserted between the fluted roller and the blank, reduces the amount of seed necessary to fill the feed before it starts delivering to the ground. The hopper on top of the feed can be made of any size desirable. A size which will hold enough seed for 3 rods of row is convenient. When operating, the seed is delivered from the feed through a tin tube into the furrow opened by the shoe of the seeder. The shoe on the seeder used

in building the drill described is 3 inches long by 1 inch in width. A box to carry seed envelopes and a pointed spike for empty envelopes are fitted to the machine.

FIG. 1.—A cereal nursery seeder consisting of a fluted feed from an ordinary grain drill mounted on a garden seeder.

The seeder works best in a seedbed that is moderately firm and free from clods. The ground is first marked off in rows 1 foot apart, the series being then marked off for whatever length of row plus whatever width of alley is desired. Alleys 3 to 4 feet in width are desirable as they give sufficient room for starting and turning the machine. After the seed has been put in the hopper the front wheel should be turned until the grain starts falling down the tin tube. A half to a three-quarters turn will be sufficient for this purpose. In seeding, the shoe should be started in the center of the alley, because the machine will have moved a short distance before the first seeds strike the furrow. The seed in the furrow is covered and packed by the rear wheel of the seeder. After the row is seeded, the hopper and feed are cleaned by raising the hinged board to a vertical position, and revolving the fluted roller in the reverse direction about a half revolution. After emergence the rows are trimmed to a uniform length.

FIG. 2.—Cereal nursery seeder showing hopper and feed in position for cleaning.

When single rod rows are seeded, one man can sow 1,000 rows in one day with this machine. Where the three-row block system is used about 1,500 rows can be sown in one day.—G. A. WIEBE, *U. S. Dept. of Agriculture, Washington, D. C.*

# AGRONOMIC AFFAIRS

## THE INTERNATIONAL SOIL CONGRESS

We are indebted to the American Society for Cultural Relations with Russia for the following information relative to the International Soil Congress to be held in Russia in 1930.

Professor Yarilov, Secretary of the Russian Committee on arrangements, has announced that the Congress will take place from June 1 to 11, partly in Moscow and partly in Leningrad. From June 11 to 27 there will be excursions to the Caucasus, the Ukraine, etc., including a trip down the Volga. Special excursions will be arranged for those interested in visiting Crimea, Siberia, and Central Asia. Participation in the Congress is open to all members of the International Society of Soil Science, and the program of the Congress will embrace soil science, agronomy, geography, geology, climatology, etc. A general committee of representatives of the several state agricultural colleges and experiment stations is to be appointed to assist the American Society for Cultural Relations with Russia in the organization of the American delegation to the Congress. Information as to details of the program, cost of tours, and other matters may be obtained by addressing the Society at 22 East 55th Street, New York City.

## THE ANNUAL MEETING

Secretary Brown has made arrangements with the Central Passenger Association, the Southwestern Passenger Association, the Trunk Line Association, the Transcontinental Western Passenger Association, and the New England Passenger Association for reduced fares on the certificate plan for the annual meeting of the Society in Chicago. This means that if a minimum of 150 attend the meeting and present certificates, transportation to and from Chicago may be had at a fare and a half. Members of the Society should buy one-way tickets and procure a certificate from the ticket agent for validation in Chicago, entitling the holder to a return ticket at half fare.

President Funchess has announced that on the Friday afternoon, November 15, of the annual meeting of the Society there will be a general program for the presentation of papers by members of the Society. Those desiring to present papers at that time are requested to communicate with the Secretary, Dr. P. E. Brown, at Iowa State College, as soon as possible, giving the title of the paper, the time required for presentation, and whether or not lantern slides or charts will be shown.

## NEWS ITEMS

C. V. RUZEK has returned to Oregon State Agricultural College after a year spent in graduate study at the University of Wisconsin.

R. E. STEPHENSON, associate professor of soils at Oregon State College, left July 1 on sabbatical leave and is spending the summer in California. He expects to take up some special research problem later, probably in Washington, D. C.

M. M. DIEHM, a 1929 graduate of Purdue University, has been appointed to the Research Fellowship of the Chilean Nitrate of Soda Educational Bureau in the Department of Agronomy, Purdue University Agricultural Experiment Station, to succeed Frank Moser, who resigned July 1. Mr. Moser, who held this fellowship for two years, received his master's degree in June. Mr. Diehm will continue the studies started by Mr. Moser on the effects of nitrate of soda on the yield, composition, and quality of corn, wheat, and timothy with special reference to top dressing.

W. W. WORZELLA, a 1929 graduate of the University of Wisconsin, has been appointed to the National Milling Company Research Fellowship in the Department of Agronomy, Purdue University Agricultural Experiment Station, effective July 1. Mr. Worzella will give special attention to the improvement of soft red winter wheats.

B. C. LANGLEY, a 1929 graduate of the A. & M. College of Texas, has been appointed to the Fellowship established by the Educational Bureau, Chilean Nitrate of Soda, at the Texas Agricultural Experiment Station in 1927 for the purpose of studying the effect of nitrogen on the soil and on the cotton plant.

E. B. REYNOLDS, Chief of the Division of Agronomy in the Texas Agricultural Experiment Station, received the Ph.D. degree at the Iowa State College in June.

THE DEGREE of Doctor of Philosophy in Agronomy was conferred by the University of Illinois in June on W. R. Paden in soil biology and Collins Veatch in plant breeding.

AT THE annual meeting of the Western Society of Soil Scientists, held in Berkeley, June 17 and 18, an invitation was accepted to hold the next annual meeting of the Society at the Oregon State Agricultural College. A standing committee, consisting of Dr. Halverson, Oregon State College, Dr. Bachelor, Riverside, Calif., and Dr. McFarlane, Berkeley, Calif., was appointed to consider the attitude of the Society toward the patenting of fertilizer materials. New officers of the Society were elected as follows: W. L. Powers, Oregon State College, *President;* H. P. Magnuson, University of Idaho, *Vice-President;* and J. C. Martin, University of California, *Secretary.*

BERT BALL, for the past several years associated with the National Crop Improvement Committee as a publicity agent in their campaigns for the improvement of cereal crops and the control of cereal diseases, died suddenly from an attack of heart disease at St. Louis, Mo., in February, 1929.

C. W. WARBURTON, Director of Extension Work in the U. S. Department of Agriculture, has spent much time during the winter and spring months in the supervision of hurricane relief in Porto Rico, and of flood and hurricane relief in the southeastern states. The Department of Agriculture, under authorization of Congress, has been engaged in recent weeks in the making of loans to farmers in the southeastern states for the purchase of seed and fertilizer and feed for work stock. The basis for these loans was crop failures or damage to crops from storms and floods last year. The appropriation was made available on March 4, the first loan was made on March 18, and on May 15, more than 20,000 loans had been made in a total amount of more than $5,500,000. Applications for loans were handled at the temporary office of the Department located at Columbia, South Carolina, of which L. Emory White was in charge.

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# DISTRIBUTION OF ANTHOCYAN PIGMENTS IN RICE VARIETIES[1]

JENKIN W. JONES[2]

## INTRODUCTION

Anthocyan pigments occur quite commonly in the stems, leaves, leaf-sheaths, floral organs, and other parts of the rice plant. Those parts of the rice plant which are colored, due to the presence of anthocyan pigments, may be red, reddish-purple, purple, or purplish-black. The colors of parts of the rice plant often are used in the description and classification of varieties.

Several investigators have studied the mode of inheritance of the anthocyan pigments in rice. These studies have shown that the colors of organs in the rice plant are inherited in accordance with Mendel's laws. The color present in a given organ may be due to the action or interaction of one, two, or three, and less often, four, genetic factors. When two or more genetic factors are involved in the production of color such factors often are found to be complementary. In fact, all colors in organs of rice which are due to anthocyan pigments, even in the simplest monohybrids, apparently are the result of the interaction of at least two genetic factors. One of these is a factor for the chromogen base and the other a factor for the particular color under observation. Often the color in several organs of the variety under investigation has been found to be inherited as a unit, as if the colors of all the organs in the group were due to the same genetic factor or factors.

Hector[3] grouped the rices studied at Dacca, India, with respect to color as follows:

1. "Leaf-sheaths, apiculus of the glumes (apiculas of lemma and palea), and stigma coloured."

[1]Contribution from the Office of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture, in cooperation with the California Agricultural Experiment Station. Received for publication March 15, 1929.

[2]Senior Agronomist and Superintendent of the Biggs Rice Field Station, Biggs, Calif.

[3]HECTOR, G. P. Observations on the inheritance of anthocyan pigment in paddy varieties. India Dept. Agr. Mem., Bot. Ser., 8:89–101. 1916.

2. "Leaf-sheath and apiculus of glumes (apiculas of lemma and palea), coloured, but stigma colourless (white)."

3. Apiculus of glumes (apiculas of lemma and palea) and stigma coloured, but leaf-sheaths colourless."

4. "Apliculus of glumes (apiculas of lemma and palea) only coloured."

However, most of the rice varieties in India are devoid of anthocyan pigments and all their organs normally are wholly green during the vegetative period. Most of the colored varieties at Dacca were found in groups 1 and 2, whereas there were but few varieties in groups 3 and 4. Hector himself says (pp. 89–90),

"It is somewhat doubtful if classes 3 and 4 really exist. The apparent absence of colour in the leaf-sheath in these cases may, as is suggested by Graham with reference to Central Provinces' varieties, perhaps be due to the fact that the colour is of so faint and fleeting a nature as to escape detection, more especially so as the intensity of the colour appears to be considerably affected by environmental conditions."

Hector[4] in a later paper reports that the most common rices fall into the group characterized by colored leaf-sheaths, glume tips, and inner glumes (lemma and palea). This combination was present in 162 of 211 varieties examined. Colored leaf-sheaths, glume tips, and internodes were present in 154 of the 211 varieties examined, and colored leaf-sheaths, glume tips, and stigmas were present in 98 of the 211 varieties studied. By "glume tips" he probably means not only the apiculas or lemma and paleas, but also some of the apical tissues of these glumes which often become colored.

Nagai[5] reports that most of the rice varieties grown in Japan are uncolored (green) during the vegetative period. He states that in varieties which have red or purple awns, the awns are green while the panicles remain inclosed by the leaf-sheaths. Shortly after emergence from the sheath the red color begins to develop, first at the top and base of the awn. The awns finally purple are red in the beginning, but rapidly change to purple. The development of pigment in the awns appears, therefore, to be dependent upon illumination. In the stigma, of certain varieties at least, the purple pigment is present when the spikelets are still inclosed by the leaf-sheaths and the stigma is still within the lemma and palea. The development of anthocyan, therefore, appears to have a different physiological requirement in the stigma and in other floral organs of the same plants.

[4]HECTOR, G. P. Correlation of colour characters in rice. India Dept. Agr. Mem., Bot. Ser., 11:153–183. 1922.

[5]NAGAI, I. A genetico-physiological study on the formation of anthocyanin and brown pigments in plants. II. Genetical study. Jour. Col. Agr., Imp. Univ. Tokyo, 8:35–48. 1921.

In the United States all the organs of the commercial rice varieties normally are green during the vegetative period.

## MATERIAL USED

In 1925 the writer collected rice varieties in Japan, Korea, China, Java, and the Philippine Islands. The varieties collected in these countries were grown under detention at Shafter, Calif., in 1926, and those that matured at Shafter were grown at the Biggs Rice Field Station, Biggs, Calif., in 1927.

During the growing season of 1927 observations were made on the distribution of colored pigments in all of these rice varieties. There were 781 Japanese varieties and strains, 59 Korean varieties, and 140 Chinese varieties included in these observations.

## TERMINOLOGY OF GLUMES AND THEIR PARTS[6]

In many papers discussing rice varieties, the terminology of the various glumes is confusing. The two small glumes at the base of the spikelet are referred to variously as outer glumes, lower glumes, empty glumes, sterile glumes, or glumes I and II. The lemma and palea, which enclose the flower and subsequently the kernel, are referred to variously as the inner glumes, upper glumes, floral glumes, and glumes III and IV. In conformity with accepted American usage, the first pair, or outer glumes, will be designated simply as glumes, and the two floral glumes will be designated as lemma and palea, respectively.

The short excurrent tips of the major fibrovascular bundles of the floral glumes, of which the lemma bears usually one but sometimes three, and the palea one, have been referred to by many writers on Oriental rices as the "apiculus of the glumes." The term seems to be used wholly in the singular (apiculus), probably because both plural forms, namely, the Latin *apiculi*, and the English apiculuses, are undesirable. For this reason, the other recognized equivalent Latin designation, *apicula*, and its simple and desirable English plural, apiculas, are used in the present paper.

In rice varieties having the vascular apiculas colored, the pigment frequently extends to the immediately adjacent or subtending parenchymatous tissue at the apex of the lemma and the palea. To designate both sets of tissues, the phrases "glume tips" and "glume apexes" have been used by writers abroad. In the present paper these combined tissues are distinguished as lemma and palea apexes. It is hoped that this distinctive use of terms will appeal to all agronomists and botanists discussing rice varieties.

[6]The writer is indebted to Dr. C. R. Ball for assistance in working out a satisfactory terminology for these organs.

TABLE 1.—*Forty-eight numerical groups of rice varieties and strains from Japan, Korea, and China, showing, for each group, the number of colored organs, the number of lots from each country, and the total number, and the names of organs in which color developed when grown at Biggs, Calif., in 1927.*

| Number of organs colored | Group No. | Number of varieties from Japan | Korea | China | Total | Organs developing color |
|---|---|---|---|---|---|---|
| | 1 | 0 | 1 | 0 | 1 | Awns |
| 1 | 2 | 5 | 0 | 1 | 6 | Lemma and palea apexes |
| | 3 | 2 | 3 | 13 | 18 | Lemmas and paleas |
| | 4 | 2 | 0 | 0 | 2 | Stigmas |
| | 5 | 44 | 1 | 0 | 45 | Lemma and palea apexes, and awns |
| | 6 | 1 | 0 | 0 | 1 | Lemma and palea apexes, and stigmas |
| | 7 | 32 | 1 | 0 | 33 | Lemma and palea apexes, and glumes |
| 2 | 8 | 5 | 1 | 0 | 6 | Lemmas and paleas, and awns |
| | 9 | 0 | 1 | 0 | 1 | Glumes and awns |
| | 10 | 1 | 0 | 0 | 1 | Stigmas, and internodes |
| | 11 | 1 | 3 | 0 | 4 | Lemmas and paleas, and glumes |
| | 12 | 83 | 6 | 0 | 89 | Lemma and palea apexes, awns, and glumes |
| | 13 | 6 | 0 | 0 | 6 | Lemma and palea apexes, awns, and stigmas |
| | 14 | 4 | 0 | 0 | 4 | Lemma and palea apexes, glumes, and stigmas |
| 3 | 15 | 0 | 0 | 1 | 1 | Lemma and palea apexes, auricles, and stigmas |
| | 16 | 5 | 1 | 0 | 6 | Lemmas and paleas, awns, and glumes |
| | 17 | 1 | 0 | 0 | 1 | Lemmas and paleas, glumes, and stigmas |
| | 18 | 0 | 2 | 0 | 2 | Lemmas and paleas, glumes, and internodes |
| | 19 | 29 | 0 | 0 | 29 | Lemma and palea apexes, glumes, awns, and stigmas |
| 4 | 20 | 0 | 0 | 1 | 1 | Lemma and palea apexes, stigmas, leaf-sheaths, and internodes |
| | 21 | 8 | 0 | 0 | 8 | Lemma and paleas, glumes, awns, and stigmas |
| | 22 | 2 | 0 | 0 | 2 | Lemma and palea apexes, glumes, awns, internodes, and stigmas |
| | 23 | 1 | 0 | 0 | 1 | Lemma and palea apexes, glumes, awns, leaf-sheaths, and stigmas |

| | | | | | | |
|---|---|---|---|---|---|---|
| | 24 | 1 | 0 | 0 | 1 | Lemma and palea apexes, glumes, leaf-sheaths, internodes, and stigmas |
| 5 | 25 | 0 | 0 | 2 | 2 | Lemma and palea apexes, leaf-sheaths, auricles, nodes, and stigmas |
| | 26 | 0 | 1 | 0 | 1 | Lemmas and paleas, awns, leaf-sheaths, internodes, and nodes |
| | 27 | 1 | 0 | 0 | 1 | Lemmas and paleas, glumes, leaf-sheaths, internodes, and stigmas |
| | 28 | 2 | 0 | 0 | 2 | Lemmas and paleas, glumes, awns, leaf-sheaths and stigmas |
| | 29 | 3 | 0 | 0 | 3 | Lemma and palea apexes, glumes, awns, leaf-sheaths, internodes, and stigmas |
| | 30 | 2 | 1 | 0 | 3 | Lemma and palea apexes, glumes, awns, leaves, leaf-sheaths, and stigmas |
| | 31 | 1 | 0 | 0 | 1 | Lemma and palea apexes, glumes, leaves, leaf-sheaths, internodes, and stigmas |
| 6 | 32 | 0 | 0 | 2 | 2 | Lemma and palea apexes, leaves, leaf-sheaths, auricles, nodes, and stigmas |
| | 33 | 0 | 0 | 1 | 1 | Lemma and palea apexes, leaves, auricles, internodes, nodes, and stigmas |
| | 34 | 1 | 0 | 0 | 1 | Lemmas and paleas, glumes, awns, leaf-sheaths, internodes and stigmas |
| | 35 | 0 | 2 | 0 | 2 | Lemmas and paleas, glumes, awns, leaves, internodes, and nodes |
| | 36 | 0 | 0 | 1 | 1 | Lemmas and paleas, leaves, leaf-sheaths, auricles, nodes, and stigmas |
| | 37 | 1 | 1 | 0 | 2 | Lemma and palea apexes, glumes, awns, leaves, leaf-sheaths, internodes and stigmas |
| | 38 | 0 | 1 | 0 | 1 | Lemma and palea apexes, awns, leaves, ligules, auricles, nodes and stigmas |
| | 39 | 0 | 1 | 0 | 1 | Lemmas and paleas, leaves, leaf-sheaths, ligules, auricles, internodes, and nodes |

TABLE 1.—*Continued.*

| Number of organs colored | Group No. | Number of varieties from Japan | Korea | China | Total | Organs developing color |
|---|---|---|---|---|---|---|
| 7 | 40 | 3 | 0 | 0 | 3 | Lemmas and paleas, glumes, awns, leaves, leaf-sheaths, internodes, and stigmas |
| | 41 | 0 | 0 | 1 | 1 | Lemmas and paleas, glumes, leaf-sheaths, auricles, internodes, nodes, and stigmas |
| | 42 | 0 | 1 | 0 | 1 | Leaves. leaf-sheaths, ligules, auricles, internodes, nodes and stigmas |
| 8 | 43 | 0 | 0 | 1 | 1 | Lemma and palea apexes, leaves, leaf-sheaths, ligules, auricles, internodes, nodes and stigmas |
| | 44 | 0 | 1 | 0 | 1 | Lemmas and paleas, leaves, leaf-sheaths, ligules, auricles, internodes, nodes and stigmas |
| 9 | 45 | 0 | 2 | 0 | 2 | Lemma and palea apexes, glumes, awns, leaves, leaf-sheaths, ligules, auricles, nodes, and stigmas |
| | 46 | 0 | 1 | 0 | 1 | Lemmas and paleas, glumes, awns, leaves, leaf-sheaths, ligules, auricles, internodes, and stigmas |
| 10 | 47 | 1 | 4 | 0 | 5 | Lemma and palea apexes, glumes, awns, leaves, leaf-sheaths, ligules, auricles, internodes, nodes, and stigmas |
| | 48 | 0 | 3 | 0 | 3 | Lemmas and paleas, glumes, awns, leaves, leaf-sheaths, ligules, auricles, internodes, nodes, and stigmas |
| **Total** | | 248 | 39 | 24 | 311 | |

## COLORED ORGANS STUDIED

The internodes, nodes, leaf-sheaths, leaf blades, ligules, auricles, glumes (outer or empty glumes), lemmas and paleas (inner or floral glumes), lemma and palea apexes (apiculas and adjacent tissue), awns, and stigmas were examined for color before and after the plants reached maturity. Of the 980 varieties and strains under observation, 311 had color in one or more of the above-named organs. A total of 669 varieties and strains, or more than two-thirds of the varieties, had no color in any of the organs under observation.

The 980 varieties and strains under observation fell into 48 groups with respect to the distribution of color in the various organs studied.

There were four groups, containing a total of 27 varieties, with some one organ colored; seven groups, containing a total of 91 varieties, with some two organs colored; seven groups, in which were 109 varieties, with some three organs colored; three groups, containing a total of 38 varieties, with some four organs colored; seven groups, in which were 10 varieties, with some five organs colored; eight groups, in which were 14 varieties, with some six organs colored; six groups, in which were 9 varieties, with seven organs colored; two groups, in which were 2 varieties, with some eight organs colored; two groups, in which were 3 varieties, with some nine organs colored; and two groups, in which were 8 varieties, with some 10 organs colored.

In Table 1 the 48 groups are listed in numerical order and for each group is given the number of varieties and strains obtained from Japan, Korea, and China, respectively, the total number, and the organ or organs in which color develops.

The most common color group was No. 12, containing 89 varieties characterized by colored glumes, lemma and palea apexes, and awns. The color group second in importance was group 5, containing 45 varieties having colored lemma and palea apexes and awns. The third group in numerical importance was group 7 with 33 varieties having colored glumes, and lemma and palea apexes. The fourth group in numerical importance was group 19, containing 29 varieties with colored glumes, lemma and palea apexes, awns, and stigma. The fifth group in numerical importance was group 3, containing 18 varieties with colored lemmas and paleas, the colors involved being yellow and brown. Two hundred and fourteen of the 311 varieties with colored organs fell into these five groups.

In the segregation of particular rice crosses, in which varieties with certain color combinations were crossed with normally green varieties, Hector[7] reports that certain color combinations, which were expected if independent segregation were taking place, were not

[7] *Loc. cit.*

obtained. The combinations that were absent in the segregating progenies were absent also in the rice varieties examined at Dacca, India. He reports that no segregates were obtained which had colored internodes, leaf-sheaths, and stigmas with "green apicullus." In the collection observed in the present study one Korean variety of color group 42 had colorless (green) lemma and palea apexes with colored *internodes*, nodes, leaf blades, *leaf-sheaths*, auricles, ligules, and *stigmas*.

Other color combinations which were absent in the segregates from Hector's crosses were: Colored glumes with green leaf-sheaths and lemma and palea apexes, and stigmas, and colored glumes with green lemma and palea apexes. In this study one variety from Korea, in group 9, was observed to have *colored glumes* and uncolored *internodes*, *leaf-sheaths*, *lemma and palea apexes*, and *stigmas*. Hector also reported the absence in his segregates of colored internodes and stigmas with green leaf-sheaths, and lemma and palea apexes. A variety from Japan, in group 10, had colored *internodes* and *stigmas* with green leaf-sheaths and apexes of lemmas and paleas.

Hector's results show that independent segregation did not take place in his crosses. From the results presented here, however, it seems likely that the examination of enough material probably would bring to light all of the possible color combinations. It appears, therefore, that while certain color combinations are linked in inheritance there probably is a small amount of crossing over. This may result in varieties having the color combinations reported absent in the segregates grown by Hector, but a few of which were present in certain varieties obtained by the writer from Japan and Korea, as noted above.

## DISCUSSION

In these studies it was noted that the red and purple colors of rice organs were of various shades and intensities. The red color in the glumes, lemmas, paleas, lemma and palea apexes, and awns may be bright red, pinkish red, orange red, or brick red. In certain varieties the red color is very distinct and may be present in the lemma and palea apexes and often in the glumes at the time the panicles emerge from the leaf-sheaths. However, in other varieties the red color in the lemma and palea apexes and in the glumes is not present at panicle emergence, but develops later. In some varieties the red color in the lemma and palea apexes and awns may disappear at maturity. In other varieties the red color in these organs does not fade out at maturity.

Of all the varieties under observation which had red lemma and palea apexes and red glumes, none were found that had red stigmas. Some of the varieties with red floral-glume apexes and glumes did

There was one variety from Korea, in group 1, which had red awns on uncolored (green) apexes of lemmas and paleas.

The purple and red color in the vegetative organs of the rice plant is most distinct, as a rule, before the plants reach the heading stage. Illumination seems quite necessary for the full development or expression of the color in all the organs except the stigma. For example, in varieties ordinarily showing color, the nodes which remain inclosed by the leaf-sheaths often do not develop color, whereas color does develop in those nodes which have emerged from the sheaths and are exposed to the sunlight. However, the purple stigma does not appear to be dependent upon illumination for its expression. In certain varieties that have purple stigmas these are deep purple even while the panicles still are inclosed by the leaf-sheaths. In many varieties the purple stigma can be easily seen through the lemmas and paleas before the spikelets bloom.

All the varieties in the collection under observation which had purple apexes or entire surfaces or lemmas and paleas also had purple stigmas. A few of the varieties with red-tipped lemmas and paleas also had purple stigmas. The stigmas of some varieties while young are reddish purple in color. The common color is dark purple. Two varieties were observed which had dark purple stigmas with all other plant organs normally green in color.

The color in the lemmas and paleas of the varieties placed in group 3 apparently was not due to anthocyan pigments, for these organs were yellow, yellowish brown, or brown in color.

The lemmas and paleas themselves, and their apexes, are in reality the same organ and, of course, varieties which have these organs colored also have their apexes colored. There are many varieties, however, in which only the apexes are colored.

The fact that the same anthocyan pigment may be present in one or in differing numbers of organs suggests that the color in the different organs may be due to different genetic factors. The results of several genetic studies dealing with the anthocyan pigments in rice indicate, however, that the color in certain organs appears to be due to the same genetic factor or factors, or to linked factors.

## AWNEDNESS

Of the 781 Japanese rice varieties under observation, 67 were fully awned, 440 were partly awned, and 274 were awnless. Of the 59 Korean rice varieties under observation, 29 varieties were fully awned, 21 were partly awned, and 9 were awnless. Of the 140 Chinese rice varieties under observation, 3 were fully awned, 26 were partly awned, and 111 were awnless.

# INHERITANCE OF LINT PERCENTAGE IN COTTON[1]

J. O. WARE[2]

Lint percentage is an important consideration in the production of cotton. Varieties of cotton that yield a high gin out-turn have always attracted the attention of the farmer. The cotton that produces the greatest number of pounds of lint to the acre, provided the fiber is of good quality, has brought more money returns from an acre than low lint percentage varieties unless the latter were of the long staple type and commanded a high premium for the extra length. High gin out-turn does not correlate with long staple and the long staple growers do not expect high lint percentages, but with the short staple farmer high lint yield is a prime requisite.

In the development of new strains of cotton the plant breeder attempts to raise the lint percentage in long staple cotton as much as can be maintained without losing the primary qualities sought, but with the short staple high lint percentage is one of the chief aims. In all plant selection work with cotton the lint percentage of the plant has to be taken into account. Plants are selected which are thought to produce the length of lint desired in the new strain. It is not known whether or not a given plant will produce progeny with uniform lint percentages because the inheritance of lint percentage is a quantitative character and the scheme of character transmission is not very well understood. Definite numerical ratios with quantitative characters are much more difficult to establish than with qualitative characters. Quantitative characters non-heritably fluctuate so much that they can not be graded and classified into qualitative groups unless the characters entering into the class are widely separated on the scale of measurement for these characters and then not always with clear cut distinction.

The object of this paper is to report some lint percentage inheritance studies carried on at the Arkansas Agricultural Experiment Station. This work involves a study of crosses made between plants at four degrees of difference in lint percentage. It was thought that with the extreme lint percentage crosses which are represented by hybrids of a sparse or scant lint variety and high lint percentage varieties a Mendelian ratio could be obtained which would throw light on the inheritance of lint percentage in general.

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## METHOD OF WORK

The four degrees of difference in percentage are represented by four groups of crosses. These groups or sets of crosses are designated as A, B, C, and D. The means of the A parents differed in lint percentage by 0.93, the B parents by 7.38, the C parents by 9.90, and the D parents by 28.76.

The A crosses were between three Pima plants (Egyptian type, *Gossypium barbadense*) used as females and one Winesap plant (Upland type, *G. hirsutum*) used as the male. The B crosses were between two Pima plants used as females and one Upright plant (Upland type) used as the male. The C cross was between one Sea Island plant (Sea Island type, *G. barbadense*) used as female and one Winesap plant used as the male. The D crosses were between several scant lint (Texas No Lint, an Uplandt ype, Fig. 5) and several normal lint plants (three varieties of the Upland type, Winesap, Upright, and Sproul). The actual crosses were as follows:

1. ♀ Winesap x ♂ Scant lint (three crosses)
2. ♀ Scant lint x ♂ Winesap (one cross)
3. ♀ Scant lint x ♂ Upright (five crosses)
4. ♀ Scant lint x ♂ Sproull (three crosses)

The work with the A, B, and C crosses was started in 1921. As artificial pollinations were being made, both the plants used as females and those used as the males were selfed. Plants from the selfed and crossed seed were grown in 1922. The progeny of the original parental plants were designated as parental strains in 1922 and 1923. In 1922, back crosses were made between the $F_1$'s of each set of crosses and their two respective parental strains. New $F_1$ crosses between the respective parental strains were also made to furnish additional $F_1$ material. These new $F_1$ crosses were designated as re-crosses in 1923. The $F_1$ plants, the parental strain plants which were re-crossed, and some additional parental strain plants were selfed in 1922. Plants from the back crossed seed, the re-crossed, and the selfed seed were grown in 1923. Parental strain, $F_1$, back cross, and $F_2$ plants were grown the same year. All generations had similar seasonal conditions. However, the data from the parental strains and $F_1$'s of the 1922 growth were similar to the results obtained from the respective parental strains and $F_1$'s (re-crosses) of 1923. The 1922 data were added in with like populations in the 1923 results.

With the re-crosses and the back crosses reciprocals in almost every case were made, but there was apparently no difference between direct and reciprocal crossing. The direct and reciprocal crosses were combined.

The $F_3$ generation of the A, B, and C crosses were grown in 1924, but very little reliable data were obtained. The season was rather poor for late cottons like Pima, Sea Island, or any hybrids which showed considerable tendency toward the *G. barbadense* species. The stand was very poor and many of the plants that did grow were

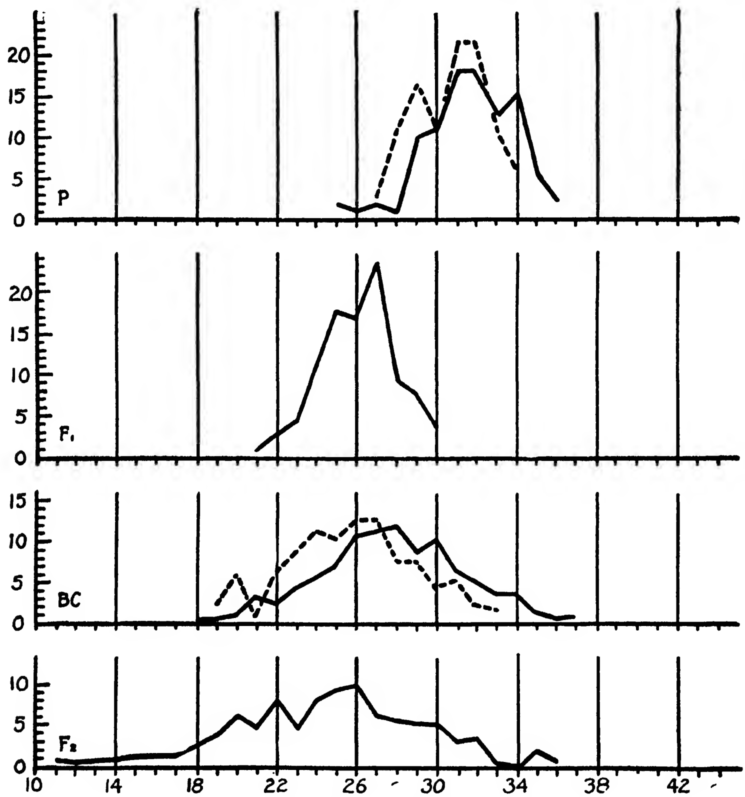


FIG. 1.—A crosses, Pima x Winesap.

The ordinate figures indicate the number of plants as a percentage of the total population. The abscissa figures denote the percentage of lint. In the P section of the graph the dotted curve line represents the Pima population and the solid curve line the Winesap population. In the BC section of the graph the dotted curve line represents the population from the back cross on the Pima parental strain and the solid curve line the population from the back cross on the Winesap parental strain.

sterile or shed their flower buds and bolls before maturity. In an Upland-Egyptian hybrid, Kearney (1, pp. 41–44)[3] has reported 7% sterility and a low degree of fertility in many of the $F_2$ generation plants; poor germination in the $F_3$, due to low viability of many of

[3]Reference by number is to "Literature Cited," p. 894.

the $F_2$ generation seeds; and a further decline in the degree of fertility and more sterility in the $F_3$ generation.

The original D crosses were made in 1922 and the same methods used as with the A, B, and C crosses, but the material was grown in

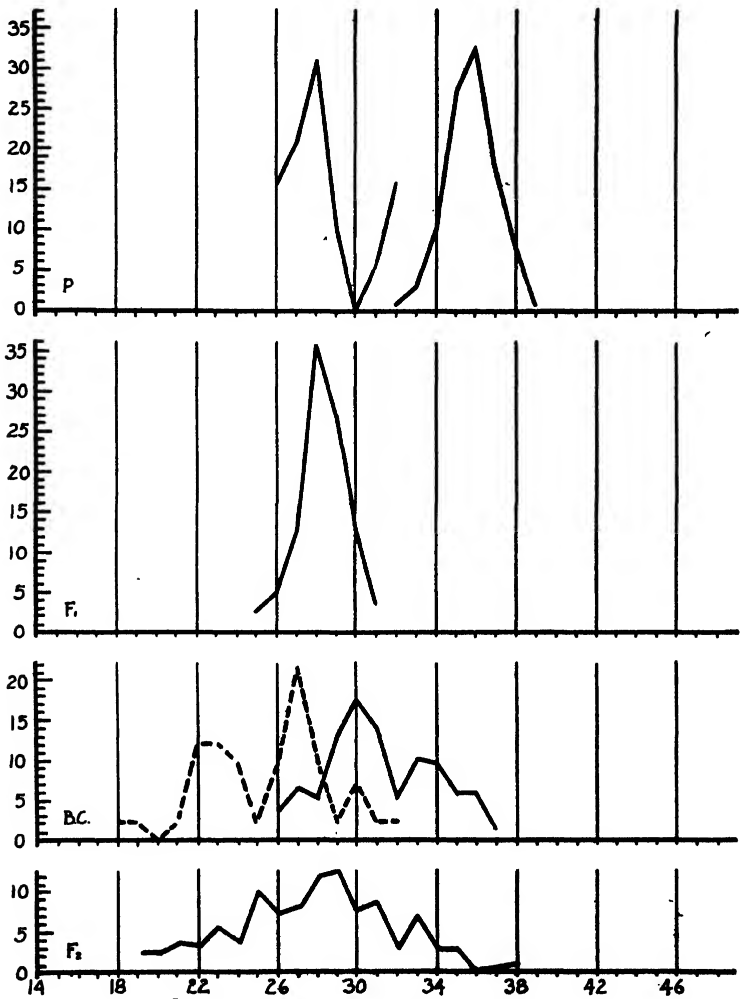


FIG. 2.—B crosses, Pima x Upright.

The ordinate figures indicate the number of plants as a percentage of the total population. The abscissa figures denote the percentage of lint. The left curve line in the P section of the graph represents the Pima population and the right curve line the Upright. The dotted curve line in the BC section of the graph represents the population from the back cross on the Pima parental strain and the solid curve line the population from the back cross on the Upright parental strain.

1923 and 1924 instead of 1922 and 1923. No $F_3$ material of the D crosses is included in this paper.

The percentage of lint data were taken on all these types by ginning a small sample from each plant on the roller gin and taking the weights on a torsion balance. The data for each plant were assembled according to the group or population of each set of crosses. There were six populations in each of the A, B, and C crosses and eight in the D crosses. In the latter the progeny of one of the back crosses fell into two groups and the $F_2$ was so strongly bimodal that the two modes were treated separately. Each group is calculated statistically. The plant number frequencies in each population are converted to a percentage of the total plants of the group so that the graphs, though representing different plant numbers, became more comparable.

## RESULTS

The graphs illustrate the frequency distribution of each population and show by their positions the relationship of the $F_1$ generation, the back crosses, and the $F_2$ generation to the parental strains. The graphs of the A crosses are shown in Fig. 1, the B crosses in Fig. 2, the C crosses in Fig. 3, and the D crosses in Fig. 4. The number of plants in each population and the statistical constants appear in subsequent tables.

### POPULATION

The number of plants in each population of the A, B, C, and D crosses is given in Table 1.

TABLE 1.—*Populations in the different sets of crosses.*

| Type of population | Number of plants |
|---|---|
| A Set of Crosses | |
| Winesap parental strain | 111 |
| Pima parental strain | 37 |
| $F_1$ generation | 105 |
| Back cross on the Winesap parental strain | 353 |
| Back cross on the Pima parental strain | 133 |
| $F_2$ generation | 221 |
| Total | 960 |
| B Set of Crosses | |
| Upright parental strain | 174 |
| Pima parental strain | 19 |
| $F_1$ generation | 119 |
| Back cross on the Upright parental strain | 134 |
| Back cross on the Pima parental strain | 41 |
| $F_2$ generation | 228 |
| Total | 715 |

TABLE 1.—*Concluded.*

| Type of population | Number of plants |
|---|---|
| C Set of Crosses | |
| Winesap parental strain | 52 |
| Sea Island parental strain | 50 |
| $F_1$ generation | 62 |
| Back cross on the Winesap parental strain | 63 |
| Back cross on the Sea Island parental strain | 51 |
| $F_2$ generation | 127 |
| Total | 405 |
| D Set of Crosses | |
| Scant lint parental strain | 318 |
| Normal lint parental strain | 138 |
| $F_1$ generation | 164 |
| Back cross on scant lint, lower half | 154 |
| Back cross on scant lint, upper half | 151 |
| Back cross on normal lint | 236 |
| $F_2$ generation, lower fourth | 174 |
| $F_2$ generation, upper three-fourths | 532 |
| Total | 1,867 |
| Total for four sets of crosses | 3,947 |

## MEANS

The means and the probable errors of the means of each population in the four sets of crosses are presented in Tables 2, 3, 4, and 5. Various relationships are shown between these means in the tables.

In the A crosses the mean lint percentage of the two parental strains is practically identical, being only $0.93 \pm .24$ apart. The $F_1$ population mean is $26.35 \pm .12$. It is considerably lower than that of either parental strain. Low lint percentage in these crosses seems to be not only dominant but intensified. The mean of the population from the back cross on the lower % parental strain was slightly but not significantly lower than the $F_1$ generation mean. The mean of the population from the back cross on the higher % parental strain lies between the mean of the $F_1$ and the mean of the higher % parental strain. Segregation of high lint % plants in this population may be the cause of the higher position of the mean as low percentage dominance does not affect all the plants. The mean percentage of the $F_2$ generation is $24.72 \pm .22$. This mean is lower than the means of any of the other populations in the A crosses. Segregation of higher lint percentage plants does not apparently raise this mean. More detailed data concerning the means of the A crosses are given in Table 2.

In the B crosses the mean lint percentage of the two parental strains is 7.38±.31 apart. As in the A crosses the $F_1$ generation is lower than the mean of the lower parental strain, but the difference is so slight that it is insignificant. Low lint is dominant in the B crosses but is not intensified. Mell (3, p. 19) and McLendon (4, p. 211) reported similar results in the $F_1$ of the A and B crosses. In crosses between several Upland varieties, Mell secured $F_1$ plants

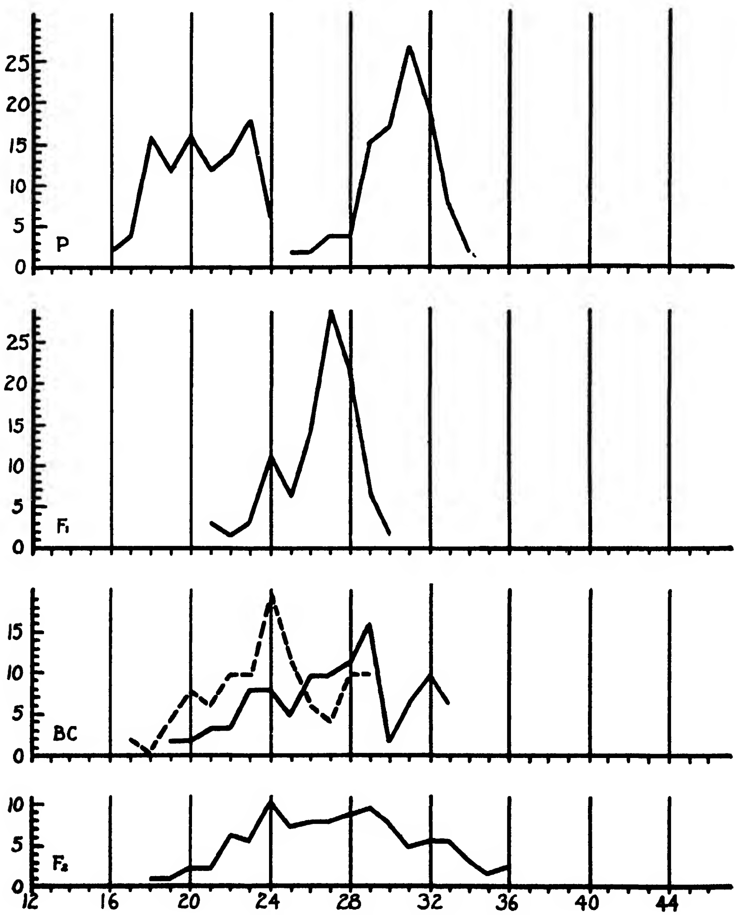


FIG. 3.—C crosses, Sea Island x Winesap.

The ordinate figures indicate the number of plants as a percentage of the total population. The abscissa figures denote the percentage of lint. The left curve line in the P section of the graph represents the Sea Island population and the right curve line the Winesap. The dotted curve line in the BC section of the graph represents the population from the back cross on the Sea Island parental strain and the solid curve line the population from the back cross on the Winesap parental strain.

which were lower in lint percentage than that of either parent. In a cross between Sea Island and Cook's Big Boll, McLendon found the $F_1$ to average below the lower parent average in lint percentage. Kearney (1, p. 12), in a Holdon-Pima cross, reports the lint index mean of the Holdon (an Upland variety) as $5.8 \pm .14$, of the Pima as $4.70 \pm .06$, and of the $F_1$ as $4.8 \pm .03$. Low amount of lint was almost completely dominant, the mean of the $F_1$ being only $0.1 \pm .07$ higher than the Pima mean. The mean percentage of the population from the back cross on the lower lint % parental strain is lower than

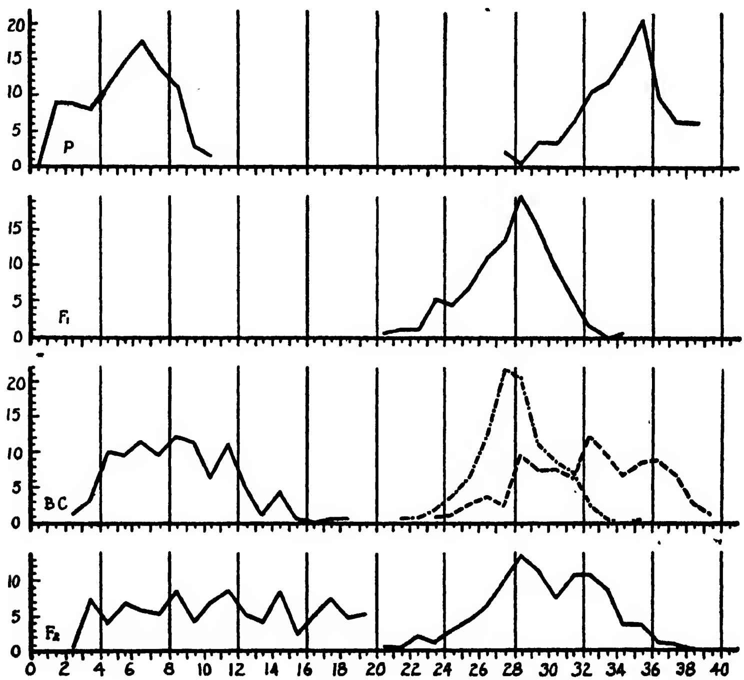


FIG. 4.—D crosses, scant lint x normal lint:

The ordinate figures indicate the number of plants as a percentage of the total population. The abscissa figures denote the percentage of lint. The left curve line in the P section of the graph represents the scant lint population and the right curve line the normal lint. The solid curve line in the BC section of the graph represents the lower half of the population from the back cross on the scant lint parental strain, the dot and dash curve line the upper half of the population from the back cross on the scant lint parental strain, and the dash curve line the population from the back cross on the normal lint parental strain. The latter distribution is the furthest to the right. The left curve line in the $F_2$ section of the graph represents the lower fourth of the $F_2$ population and the right curve line the upper three-fourths of the $F_2$ population. The percentage basis of the plant frequencies prevented the latter curve from enclosing three times the area as is enclosed by the curve of the lower fourth of the $F_2$ generation.

the mean of the $F_1$ generation by 2.85±.34. The segregation of low percentage plants and the influence of dominance are perhaps the causes of the lower position of this back cross mean. The mean of the population from the back cross on the higher % parental strain is 2.78±.8 higher than the $F_1$ generation mean and 4.63±.17 lower than the mean of the higher % parental strain. This mean assumes a similar position to that of the analogous population in the A set of crosses. Segregation of high lint percentage plants no doubt raises

TABLE 2.—*Means in the populations of the A crosses and various relationships shown by these means.*

| Type of population | Mean |
|---|---|
| Winesap parental strain (higher %) | 31.91±.14 |
| Pima parental strain (lower %) | 30.98±.20 |
| Difference between the two parental strains | 0.93±.24 |
| $F_1$ generation | 26.35±.12 |
| Difference between the $F_1$ and the lower % parental strain | 4.63±.25 |
| Difference between the $F_1$ and the higher % parental strain | 5.56±.18 |
| (a) Back cross on the higher % parental strain | 28.03±.13 |
| (b) Back cross on the lower % parental strain | 26.04±.19 |
| Difference between the two back crosses | 1.99±.23 |
| Difference between the "a" back cross and the higher % parental strain | 3.88±.19 |
| Difference between the "a" back cross and the $F_1$ | 1.68±.17 |
| Difference between the "b" back cross and the lower % parental strain | 4.94±.27 |
| Difference between the "b" back cross and the $F_1$ | 0.31±.22 |
| $F_2$ generation | 24.72±.22 |
| Difference between the $F_1$ and the $F_2$ generations | 1.63±.25 |
| Difference between the $F_2$ and the higher % parental strain | 7.19±.26 |
| Difference between the $F_2$ and the "a" back cross | 3.31±.25 |
| Difference between the $F_2$ and the low % parental strain | 6.26±.29 |
| Difference between the $F_2$ and the "b" back cross | 1.32±.29 |

the means of these back cross populations of the A and B crosses. The F population mean is 2.25±.37 higher than the mean of the back cross on the lower lint percentage parental strain and practically the same as the mean of the $F_1$ generation. More detailed data concerning the means of the B crosses are given in Table 3.

In the C crosses the means of the lint percentage of the parental strains are 9.90±.25 apart. The mean of the $F_1$ population lies at an intergrade point between the two parental means. It is 5.65±.24 higher than the lower % mean and 4.25±.22 lower than the higher % mean. This position of the $F_1$ mean suggests intermediate inheritance of the lint percentage in the first generation for the C set of crosses. The intermediate type of inheritance in the $F_1$ generation occurs with several qualitative characters in cotton (7 and 8).

TABLE 3.—*Means in the populations of the B crosses and various relationships shown by these means.*

| Type of population | Mean |
|---|---|
| Upright parental strain (higher %) | 36.00±.06 |
| Pima parental strain (lower %) | 28.62±.30 |
| Difference between the two parental strains | 7.38±.31 |
| $F_1$ generation | 28.59±.08 |
| Difference between the $F_1$ and the lower % parental strain | 0.03±.31 |
| Difference between the $F_1$ and the higher % parental strain | 7.41±.10 |
| (a) Back cross on the higher % parental strain | 31.37±.16 |
| (b) Back cross on the lower % parental strain | 25.74±.33 |
| Difference between the two back crosses | 5.63±.36 |
| Difference between the "a" back cross and the higher % parental strain | 4.63±.17 |
| Difference between the "a" back cross and the $F_1$ | 2.78±.18 |
| Difference between the "b" back cross and the lower % parental strain | 2.88±.44 |
| Difference between the "b" back cross and the $F_1$ | 2.85±.34 |
| $F_2$ generation | 27.99±.17 |
| Difference between the $F_1$ and the $F_2$ generation | 0.60±.18 |
| Difference between the $F_2$ and the higher % parental strain | 8.01±.18 |
| Difference between the $F_2$ and the "a" back cross | 3.38±.23 |
| Difference between the $F_2$ and the lower % parental strain | 0.63±.34 |
| Difference between the $F_2$ and the "b" back cross | 2.25±.37 |

TABLE 4.—*Means in the populations of the C crosses and various relationships shown by these means.*

| Type of population | Mean |
|---|---|
| Winesap parental strain (higher %) | 30.69±.17 |
| Sea Island parental strain (lower %) | 20.79±.19 |
| Difference between the two parental strains | 9.90±.25 |
| $F_1$ generation | 26.44±.15 |
| Difference between the $F_1$ and the lower % parental strain | 5.65±.24 |
| Difference between the $F_1$ and the higher % parental strain | 4.25±.22 |
| (a) Back cross on the higher % parental strain | 27.50±.30 |
| (b) Back cross on the lower % parental strain | 24.37±.27 |
| Difference between the two back crosses | 3.13±.40 |
| Difference between the "a" back cross and the higher % parental strain | 3.19±.34 |
| Difference between the "a" back cross and the $F_1$ | 1.06±.33 |
| Difference between the "b" back cross and the lower % parental strain | 3.58±.33 |
| Difference between the "b" and the $F_1$ | 2.07±.31 |
| $F_2$ generation | 27.61±.24 |
| Difference between the $F_1$ and $F_2$ generations | 1.17±.28 |
| Difference between the $F_2$ and the higher % parental strain | 3.08±.29 |
| Difference between the $F_2$ and the "a" back cross | 0.11±.38 |
| Difference between the $F_2$ and the lower % parental strain | 6.82±.30 |
| Difference between the $F_2$ and the "b" back crosses | 3.24±.36 |

The A and B crosses, which are between the Egyptian and the Upland types, are quite different from the C cross which is between Sea Island and Upland. The first two sets of crosses indicate low lint percentage dominance or intensification, while the latter shows incomplete dominance of high lint percentage. The mean of the population from the back cross on the lower % parental strain is $2.07 \pm .31$ lower than the $F_1$ mean and $3.58 \pm .33$ higher than the mean of the lower % parental strain. This back cross mean is at almost a median location between the means of the $F_1$ and the low percentage parental strain.

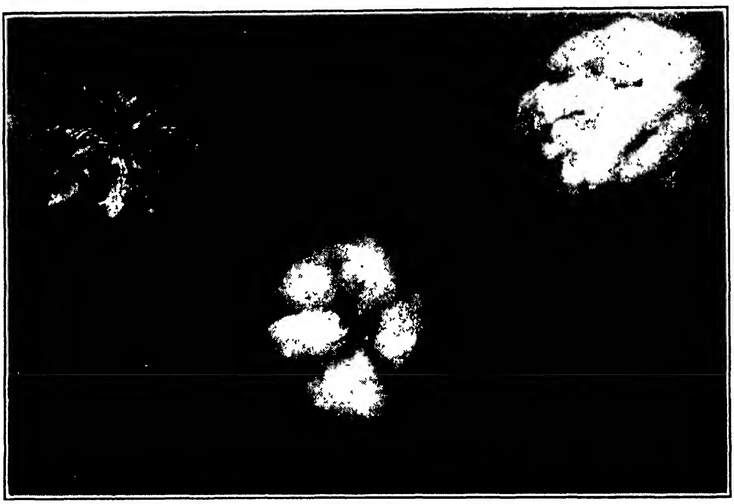

FIG. 5.—A scant lint boll on the left, a normal lint boll on the right, and an $F_1$ boll of these two types in the lower center.

The means of the population from the back cross on the lower lint % parental strain in the A and B crosses are also lower than the $F_1$ mean, but in these two sets of crosses the means of the lower % parental strains were higher or slightly higher than the $F_1$ generation mean. This back cross shows a tendency to dominance for low lint % in the A and B crosses and a tendency to dominance for high lint % in the C crosses. However, the influence of segregation and its ability to shift the mean has to be taken into account in a back cross. The mean of the population from the back cross on the higher lint % parental strain is $1.06 \pm .33$ higher than the $F_1$ population mean and $3.19 \pm .34$ lower than the mean of the higher lint % parental strain. This back cross mean takes an intermediate position between the $F_1$ mean and the high % parental mean also in the A

and B crosses. In the three cases, the back cross mean was nearer the $F_1$ mean than the higher % parental mean. Such a position of this mean does not help to explain whether low lint percentage is dominant in the A and B crosses and whether high lint percentage is incompletely dominant in the C crosses.

The $F_2$ population mean is $6.82 \pm .30$ higher than the mean of the lower % parental strain, $3.08 \pm .29$ lower than the mean of higher % parental strain, and $1.17 \pm .28$ higher than the mean of the $F_1$ population. The $F_2$ generation mean is lower than the $F_1$ generation mean in the A and B crosses, but higher than the $F_1$ generation mean in the C crosses. The $F_2$ generation mean is also much nearer the mean of the higher % parental strain in the C crosses than with the A and B crosses. The relative position of the $F_2$ population mean in the three sets of crosses seems to indicate dominance of low percentage in the A and B crosses and high percentage in the C crosses.

In the D crosses the mean lint percentages of the parental strains are $28.76 \pm .13$ apart. The mean of the $F_1$ population lies at an intergrade point betwen the means of the two parental strains. It is $22.31 \pm .16$ higher than the mean of the scant lint parental strain and $6.45 \pm .16$ lower than the mean of the normal lint parental strain. High lint percentage in the D crosses approaches dominance more nearly than in the C crosses. The $F_1$ generation mean is practically at a median point between the means of the two parental strains in the C crosses. Kottur (2, p. 116) and Thadani (5, pp. 572 and 574; 6, p. 40) report $F_1$ results similar to those of the C and D crosses. From a *G. herbaceum* (Dharwar No. 1) and *G. neglectum* var. *rosea* cross Kottur obtained mean lint percentages of 28 for the Dharwar No. 1 parent, 35.1 for the *rosea* parent, and 34.2 for the $F_1$. Thadani found a dominant condition of high lint percentage in the following crosses of Upland varieties: (a) Texas No Lint[4] x Lone Star, (b) Texas No Lint x Texas Rust, (c) Texas No Lint x Acala, and (d) Texas No Lint x Red Leaf. The mean of the population from the back cross on the normal lint parental strain is $4.51 \pm .21$ higher than the $F_1$ generation mean and $1.94 \pm .18$ lower than the mean of the normal lint parental strain. The dominance of high lint percentage prevented the segregation of any scant lint plants in this population and the group falls into one frequency distribution. Theoretically half of the plants should have a lint percentage equivalent to the $F_1$ plant percentages and the other half equivalent to the normal lint plants, but the $F_1$ distribution and the normal lint

[4]Texas No Lint is no doubt the same variety as used in the D set of crosses for the scant lint parental strain.

distribution are so near each other that there is no definite bimodal condition in the population from the back cross on the normal lint.

The jagged appearance of the curve for this population should hardly be interpreted as plurimodal. The condition is more likely to be due to fortuitous fluctuations. In the population of the back cross on the scant lint parental strain there are two separate groups each embracing practically one-half of the plants. The lower group includes 154 plants which fluctuate around a mean of $8.47 \pm .17$ and the upper group 151 plants tending to group themselves around a mean of $28.18 \pm .12$. In a 1:1 ratio theoretically the lower distribution should coincide with the frequency array of the plants in the scant lint parental strain and the upper group with the $F_1$ distribution. The upper half corresponds almost identically with the $F_1$ population, but the lower half is not as clear cut in recessiveness as the scant lint parental strain group. However, the divergence in this last respect hardly seems sufficient to warrant any conclusion other than that the ratio is 1:1.

The $F_2$ population is bimodal with practically one-fourth of the plants in the lower mode and three-fourths in the upper mode. The mean of the lower percentage mode shifted toward the scant lint parental strain and the mean of the high percentage mode toward the normal lint parental strain, but neither approximated the parental type mean. The lower mode is more variable than the scant lint parental strain. About half of the plants of the lower distribution were as sparse of lint as the parents, but the remaining plants were somewhat higher in lint percentage. There was no complete break into two frequency distributions.[5] The lower portion is separated from the upper at the 20% point on the horizontal scale as shown in Fig. 4. However, the point between the modes which contained the fewest plants is at 21.5%. The lower group contains 174 plants and the upper 532 plants. The mean percentage of the former is $11.16 \pm .24$ and the latter $29.90 \pm .09$. The lower mean is $5.61 \pm .25$ higher than the mean of the scant lint parental strain and $2.69 \pm .19$ higher than the mean of the lower portion of the back cross on the scant lint parental strain. The mean of the upper $F_2$ group is slightly higher than that of the $F_1$ generation and the upper portion of the back cross on the scant lint, but somewhat lower than the mean of the back cross on the normal lint. Further detail of the means in the D crosses is given in Table 5.

[5]Further work is being carried on to determine at what point in the percentage scale the sparse linted plants no longer breed true.

TABLE 5.—*Means in the populations of the D crosses and various relationships shown by these means.*

| Type of population | Mean |
|---|---|
| Normal lint parental strain | 34.31±.09 |
| Scant lint parental strain | 5.55±.09 |
| Difference between the two parental strains | 28.76±.13 |
| $F_1$ generation | 27.86±.13 |
| Difference between the $F_1$ and the scant lint parental strain | 22.31±.16 |
| Difference between the $F_1$ and the normal lint parental strain | 6.45±.16 |
| (a) Back crosses on the normal lint parental strains | 32.37±.16 |
| (b) Back crosses on the scant lint parental strain, upper half | 28.18±.12 |
| (c) Back crosses on the scant lint parental strain, lower half | 8.47±.17 |
| Difference between the upper and lower half, scant lint | 19.71±.21 |
| Difference between the "a" back cross and the normal lint parental strain | 1.94±.18 |
| Difference between the "a" back cross and the $F_1$ | 4.51±.21 |
| Difference between the "b" scant lint upper half back cross and the normal lint parental strain | 6.13±.16 |
| Difference between the "b" scant lint upper half back cross and the $F_1$ | 0.32±.17 |
| Difference between the "b" scant lint upper half back cross and the "a" back cross | 4.19±.20 |
| Difference between the "c" scant lint lower half back cross and the scant lint parental strain | 2.92±.19 |
| Difference between the "c" scant lint lower half back cross and the $F_1$ | 19.39±.21 |
| Difference between the "c" scant lint lower half back cross and "a" back cross | 23.90±.23 |
| $F_2$ generation | |
| Upper three-fourths | 29.90±.09 |
| Lower fourth | 11.16±.24 |
| Difference between upper three-fourths and lower fourth | 18.74±.25 |
| Difference between $F_2$ upper three-fourths and normal lint parental strain | 4.41±.13 |
| Difference between $F_2$ upper three-fourths and the $F_1$ | 2.04±.16 |
| Difference between $F_2$ upper three-fourths and the "a" back cross | 2.47±.18 |
| Difference between $F_2$ upper three-fourths and the "b" back cross, upper half | 1.72±.15 |
| Difference between $F_2$ lower fourth and the scant lint parental strain | 5.61±.25 |
| Difference between $F_2$ lower fourth and the $F_1$ | 16.70±.27 |
| Difference between $F_2$ lower fourth and the "c" back cross, lower half | 2.69±.29 |

In a well-defined 3:1 ratio with high lint percentage completely dominant, the mean of the lower fourth of the $F_2$ population should be identical with the mean of the scant lint parental strain, but with normal lint somewhat incompletely dominant and the character a quantitative one it may be possible for the recessive plants to exhibit some more variation than the original parental strain. If the degree

of intensity in characters which are graded in classifying qualitative inheritance could be measured, no doubt more variation would often be noted in Mendelian groups. The $F_2$ population distribution indicates a 3:1 ratio more nearly than any other proportion. The $F_2$ generation results, together with those of the population from the back cross on the scant lint parental strain, give strong evidence that lint percentage is determined by one pair of factors. These data, along with those of the $F_1$ population and the population from the back cross on normal lint, bring out the fact that normal lint is almost completely dominant and that scant or sparse lint is a Mendelian recessive. Thadani (6, p. 40) reports a 3:1 ratio of normal lint to sparse lint in the $F_2$ generation of Texas No Lint crossed with several other Upland varieties having normal lint. Thadani says that the ratios obtained indicate that a single factor is involved in this pair of characters, and these expectations were fulfilled in the $F_3$ generation.

## VARIATION

Variation is indicated by the standard deviation and by the frequency curves. The standard deviations of the populations of each set of crosses are given in Table 6. The frequency curves are shown graphically in Figs. 1, 2, 3, and 4.

TABLE 6.—*Standard deviations of the A, B, C, and D crosses.*

| Type of population | Standard deviation |
|---|---|
| A Crosses | |
| Pima parental strain | 1.79 |
| Winesap parental strain | 2.23 |
| $F_1$ generation | 1.91 |
| Back cross on the Pima parental strain | 3.23 |
| Back cross on the Winesap parental strain | 3.62 |
| $F_2$ generation | 4.89 |
| B Crosses | |
| Pima parental strain | 1.94 |
| Upright parental strain | 1.23 |
| $F_1$ generation | 1.25 |
| Back cross on the Pima parental strain | 3.17 |
| Back cross on the Upright parental strain | 2.74 |
| $F_2$ generation | 3.99 |
| C Crosses | |
| Sea Island parental strain | 2.09 |
| Winesap parental strain | 1.81 |
| $F_1$ generation | 1.81 |
| Back cross on the Sea Island parental strain | 2.99 |
| Back cross on the Winesap parental strain | 3.54 |
| $F_2$ generation | 4.04 |

TABLE 6.—*Concluded.*

D Crosses

| Type of population | Standard deviation |
|---|---|
| Scant lint parental strain | 2.32 |
| Normal lint parental strain | 2.50 |
| $F_1$ generation | 2.45 |
| Back cross on scant lint parental strain, lower half | 3.13 |
| Back cross on scant lint parental strain, upper half | 2.22 |
| Back cross on normal lint, parental strain | 3.67 |
| $F_2$ generation, lower fourth | 4.86 |
| $F_2$ generation, upper three-fourths | 3.34 |

The parental strains and the $F_1$'s varied less than the back cross and the $F_2$ population in each set of crosses, with one exception. The upper portion of the population from the back cross on the scant lint parental strain in the D crosses has a standard deviation slightly less than any other group in this set of crosses. The $F_1$ population in each of the four sets of crosses fluctuated as much as or more than one parental strain and less than the other parental strain. In no case did the $F_1$ vary less than either of the two respective parental strains. Any one back cross population of a given set of crosses did not vary as much as the $F_2$ generation, but both back crosses taken together showed fluctuations about as wide as the $F_2$ dispersion. This was true of all four sets of crosses. Other investigators have found that there is more variation in the $F_2$ than in the $F_1$.

Kearney (1, p. 52) states that the frequency distributions of the $F_2$ extend to and beyond the extremes of both parental populations in 33 out of 39 characters studied in a Holdon-Pima cross. The range of the lint index in the $F_1$ and $F_2$ populations was not given. However, the standard deviation of this lint determination in the $F_2$ was much larger than in the $F_1$.

McLendon (4, p. 211) states that the range of lint percentage in the $F_2$ of the Sea Island-Cook's Big Boll cross extended beyond the extremes of the parents. The range of lint percentage in the $F_2$ population went beyond the upper extreme of the high lint percentage parent only in the C set of crosses, but in the other three sets of crosses the upper limit of the $F_2$ population approximated the upper limit of the high lint percentage parent. The $F_2$ population in the A and B set of crosses went much lower in percentage than the lower limit of the low percentage parent, while the lower limit of the $F_2$ population in the C and D sets of crosses was not as low as the lower limit of the low lint percentage parental strain. The lint percentages of some of the $F_2$ generation plants are very low where low lint percentage tends to be dominant and extremely high where

high lint percentage shows dominance. In no case did the $F_2$ population extend beyond the extreme low percentage of the low parental strain and the extreme high percentage of the high parental strain.

## SUMMARY

Four sets of crosses, A, B, C, and D, were made and carried through the second generation with back crossing on the two respective parental strains in each hybrid group. A condensed tabulation of the number of individuals in each population and the statistical constants for these groups are given in Table 7. The sets of curves differed in the amount of lint percentage that the parental strains were separated. The mean percentage of the parental strains stand

TABLE 7.—*Number of individual plants in each population, means, the probable error of the means, and standard deviations of the A, B, C, and D sets of crosses.*

| Generation | Number of plants in each population | Means | Standard deviation |
|---|---|---|---|
| | A Crosses | | |
| Pima parental strain | 37 | 30.98±.20 | 1.79 |
| Winesap parental strain | 111 | 31.91±.14 | 2.23 |
| $F_1$ generation | 105 | 26.35±.12 | 1.91 |
| Back cross on Pima | 133 | 26.04±.19 | 3.23 |
| Back cross on Winesap | 353 | 28.03±.13 | 3.62 |
| $F_2$ generation | 221 | 24.72±.22 | 4.89 |
| | B Crosses | | |
| Pima parental strain | 19 | 28.62±.30 | 1.95 |
| Upright parental strain | 174 | 36.00±.06 | 1.23 |
| $F_1$ generation | 119 | 28.59±.08 | 1.25 |
| Back cross on Pima | 41 | 25.74±.33 | 3.17 |
| Back cross on Upright | 134 | 31.37±.16 | 2.74 |
| $F_2$ generation | 228 | 27.99±.17 | 3.99 |
| | C Crosses | | |
| Sea Island parental strain | 50 | 20.79±.19 | 2.09 |
| Winesap parental strain | 52 | 30.69±.17 | 1.81 |
| $F_1$ generation | 62 | 26.44±.15 | 1.81 |
| Back cross on Sea Island | 51 | 24.37±.27 | 2.99 |
| Back cross on Winesap | 63 | 27.50±.30 | 3.54 |
| $F_2$ generation | 127 | 27.61±.24 | 4.04 |
| | D Crosses | | |
| Scant lint parental strain | 318 | 5.55±.09 | 2.32 |
| Normal lint parental strain | 138 | 34.31±.09 | 2.50 |
| $F_1$ generation | 164 | 27.86±.13 | 2.45 |
| Back cross on scant lint (lower half). | 154 | 8.47±.17 | 3.13 |
| Back cross on scant lint (upper half) | 151 | 28.18±.12 | 2.22 |
| Back cross on normal lint | 236 | 32.37±.16 | 3.67 |
| $F_2$ generation lower fourth | 174 | 11.16±.24 | 4.86 |
| $F_2$ generation upper three-fourths | 532 | 29.90±.09 | 3.34 |

apart in the A crosses by 0.93±.24, in the B crosses by 7.38±.31, in the C crosses by 9.90±.25, and in the D crosses by 28.76±.16. The value of the study from the standpoint of determining parental resemblance in the offspring increases as the degree of difference between the parental means widens.

The data from the A, B, and C crosses show only tendencies in inheritance, except with the $F_1$ generation. The first generation population indicates in the A crosses not only dominance of low lint percentage but intensification of this character condition, in the B crosses complete dominance of low lint percentage, and in the C crosses incomplete or intergrade dominance of high lint percentage.

The data from the D crosses give much clearer cut evidence as to the actual transmission of lint percentage than the first three crosses. The lint percentage of the scant or sparse lint parents are so widely removed from the lint percentage of the normal lint parents that segregation appears in the population of the back cross on the recessive parents and the $F_2$ generation. High or normal lint percentage is incompletely dominant as shown in the $F_1$ generation and the population from the back cross on the normal parents. The mean of the $F_1$ population is 22.31±.16 higher than the mean of the scant lint parental strain and 6.45±.16 lower than the $F_1$ mean. The mean of the population from the back cross on the normal parents is 4.51±.21 higher than the $F_1$ mean and 1.94±.18 lower than the mean of the normal lint parental strain. The means of both the $F_1$ cross and the back cross are nearer the higher % parent than the lower % parent. The population from the back cross on the recessive or scant lint parental strain exhibits almost a perfect 1:1 ratio. This population falls into two separate distributions with 154 plants in the lower group and 151 plants in the upper group. The $F_2$ population is bimodal with practically one-fourth of the plants in the lower modal group. The two modes are not entirely separated, but the tendency is for the lower group to fluctuate around a scant lint mean somewhat higher than that of the scant lint parental strain and for the upper group to fluctuate around a normal lint mean located between the means of the $F_1$ and the normal lint parental strain. The upper distribution contains 532 plants and the lower distribution 174 plants. These numbers approximate a 3:1 ratio.

The standard deviation of the $F_1$ population is slightly less than the average of the respective parental standard deviation in the A, B, and C crosses and slightly larger than these parental averages in the D crosses. The back cross populations fluctuate more than the

$F_1$ generation or either parental strain. The $F_2$ populations exhibit more variation than any back cross on one of the parental strains, but the two back crosses taken together vary over about the same range as the plants of the $F_2$ generation. In no case does the $F_2$ population extend beyond the limit of both parental strains. In considering the limits of variation the segregated back cross and the bimodal $F_2$ of the D crosses were each taken as a single group.

Where low lint percentage is dominant, the $F_2$ generation mean tends to swing toward low percentage and where high lint percentage is of a dominant nature the mean of the $F_2$ population inclines in the direction of high lint percentage.

In the D crosses the 1:1 back cross ratio and the 3:1 $F_2$ ratio are good evidences of the single factor control of lint percentage, at least as far as scant lint and normal lint crosses are concerned. These ratios also indicate that quantitative characters would become qualitative and could be graded provided sufficient extremes in size or degree of difference in percentage could be obtained.

The information obtained from the scant lint and normal lint crosses may apply to lint percentage in general where high percentage is dominant or incompletely so, but with low lint percentage taking the dominant tendencies such inferences may not be sound.

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# THE RELATIONSHIP OF ORGANIC ROOT RESERVES AND OTHER FACTORS TO THE PERMANENCY OF ALFALFA STANDS[1]

George Janssen[2]

The alfalfa plant has received much attention and study and has been widely distributed over the farms of the United States since its introduction. The common status of opinion seems to be, however, that it is primarily adapted to the northern, northwestern, and eastern part of the United States, production in the southern states having been limited. The reasons for this limitation are not evident. The common impression, and possibly rightly so, is that it is not readily adapted to many of the acid soil regions of the South. It should be pointed out, however, that in many areas of the South soil acidity cannot be a limiting factor since it is either not present or has been corrected with lime. It is true that other natural forage crops have dominated on acid soils because they have been found to be, to some extent, more acid tolerant.

During the past few years the Arkansas Agricultural Experiment Station has given attention to the study of alfalfa and alfalfa varieties. Roughly speaking a test dealing with some of the common varieties of alfalfa over a period of five years demonstrated the fact that there was considerable reduction in stand after the first two years of cropping. A study of when, how, and why a reduction in stand occurred in these varieties was not undertaken in the first few years of the work. It was evident, however, that such varieties as Grimm, Baltic, Kansas, and in fact many of the common so-called hardy varieties maintained their stand with a greater tenacity than did the less hardy varieties similar to the Peruvian types.

In 1925, a second series of alfalfa varieties was seeded. The soil was limed and the seed was inoculated previous to planting. On this series a study was made of (a) the relation between varieties and reduction of stand, (b) the possible effect of winter injury and subsequent fungal invasion on stand, and (c) the organic root reserves as well as changes occurring in these reserves over winter and their relation to the reduction of plant stands.

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## METHODS

Generally, the alfalfa plants and varieties used in this investigation were grown on 0.1 acre field plats. The varieties of alfalfa used as well as the seeding plan are given in Fig. 1. Plant stand counts were taken in the fall and in the spring of the year. The percentage

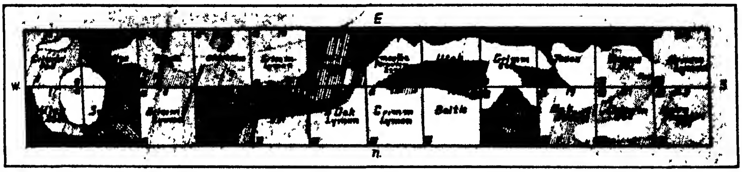

FIG. 1.—Extent of inroad of crab grass on alfalfa varieties in 1926. Density of lines indicates distribution of grass; dark squares show where yearly stand counts were taken.

of grass in the alfalfa was obtained by taking 25 pounds of the green material from the areas of soil staked out and used for taking plant counts, separating this green material into alfalfa and weeds, and calculating the percentage of each on the dry weight basis. Representative plants from each of the various varieties were taken for root development studies. The temperature and moisture records during the winter months were graphed (Fig. 2) for the two years this study was made.

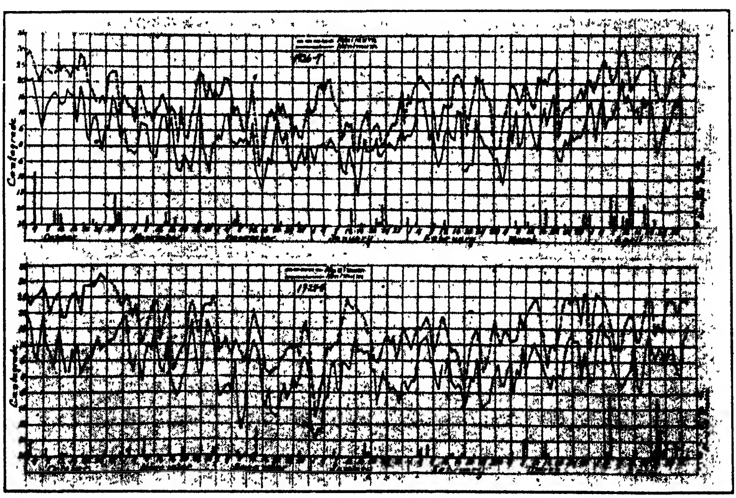

FIG. 2.—Maximum and minimum temperatures and rainfall during the fall and winter months of 1926–27 and 1927–28.

ROOT RESERVE STUDIES

The root reserve studies were made on two varieties of alfalfa grown on adjacent plats, namely, Hairy Peruvian and South Dakota Grimm. These two varieties were chosen because they showed marked contrast in root development as well as in winterhardiness. Fifty plants were used for analysis from each of the two varieties. In order to obtain comparative weights per plant, the first 8 inches of root, including the crown, was used. These roots were then cut into ¼ to ½ inch pieces and 100-gram fractions preserved in boiling alcohol for carbohydrate analysis. Fractions of 100 grams were also used in determining the dry weights of the tissue. The carbohydrate analyses, with the exception of total sugars, were made after the method described by Murneek (12),[3] MacGillivray (11), and Janssen (8). The total sugars were determined by converting all sugars into the invert form by hydrolizing for 24 hours with 2.5% HCl at a room temperature of 22–23°C. This method proved more satisfactory than hydrolizing on boiling water bath for 45 minutes.

NITROGEN FRACTIONATIONS

These fractionations were made after the method devised by Tottingham (17) and described by Murneek (12) and MacGillivray (11). Fifty-gram samples of the green roots were used in 1926–27 for making the nitrogen fractionations. This method of determining the soluble nitrogen was not used in 1927–28. The soluble nitrogen determination for samples collected that year were made on the alcoholic preserved tissue, the method of analysis being as follows: The alcohol from the preserved tissue was decanted and the tissue dried, weighed, and ground sufficiently fine to pass through an 80-mesh sieve. The container was washed with 90% alcohol and the wash collected and added to the original decanted alcohol. The alcoholic solution was then made to volume. Four grams of the dried ground sample, together with the proper aliquot of alcoholic solution, were placed in a 500 cc Erlenmeyer flask and set inside of a well-ventilated oven at 65°C. After the alcohol had been removed the tissue was boiled with 100 cc of water for three hours under a reflux condenser. The ground tissue was then filtered and washed through a Buchner filter. The filtrate was then made to volume and an aliquot used on which total nitrogen was determined by the Kjeldahl method modified to include the nitrate nitrogen.

The total nitrogen was determined on 2 grams of oven-dried plant tissue by the Kjeldahl method modified to include the nitrate nitrogen.

[3]Reference by number is to "Literature Cited," p. 910.

### ROOT DEVELOPMENT

Inspection of alfalfa roots was made from time to time for diseased or otherwise pathological symptoms.

## RESULTS

### PLANT STAND

The reduction of alfalfa plant stands seemed to take place gradually. The loss is not serious for the first two years after planting, but thereafter it is very rapid. In 1921, a series of alfalfa varieties similar to that described above was seeded. Records show that a good stand was produced, but through the gradual loss of plants from time to time the stand was depleted until in 1925 only one or two hardy northern varieties remained, and these with a poor stand. In 1925, another series of varieties was started, as already stated, and while the data on the reduction of plant stand during the first year are not at hand, the percentages of stand reduction for 1926 to 1928 are given in Table 1.

TABLE 1.—*Percentage of winterkilling of alfalfa varieties in 1926–28.*

| Plat No. | Variety | Percentage loss 1926–27 | Percentage loss 1927–28 |
|---|---|---|---|
| 1 | Utah 3332 | 1.54 | 2.21 |
| 2 | Grimm 565 | 0 | 30.92 |
| 3 | Smooth Peruvian 2274 | 0.071 | 26.92 |
| 4 | Argentine 2538 | 1.29 | 70.15 |
| 5 | Grimm Lyman 5 | 0.091 | 6.41 |
| 6 | Dakota 552 | 0 | 20.00 |
| 7 | Texas | 0 | 50.00 |
| 8 | Oklahoma | 0 | 58.91 |
| 9 | Kansas 581 | 0 | 8.16 |
| 10 | Grimm Lyman | 0 | 5.22 |
| 11 | S. D. Lyman | 0 | 13.61 |
| 12 | Hairy Peruvian 539 | 0 | 86.42 |
| 13 | Grimm Lyman | 0 | 10.20 |
| 14 | Smooth Peruvian 2274 | 0 | 49.02 |
| 15 | Baltic | 0 | 12.58 |
| 16 | Utah 3332 | 0 | 49.12 |
| 17 | Argentine 2538 | 0 | 25.00 |
| 18 | Grimm 565 | 0 | 14.38 |
| 19 | Dakota 552 | 0 | 12.79 |
| 20 | Texas | 0 | 62.90 |
| 21 | Grimm 565 | 0 | 15.57 |
| 22 | Kansas 581 | 0 | 30.76 |
| 23 | Hairy Peruvian 539 | 0 | 54.83 |
| 24 | Grimm Lyman | 0 | 20.34 |

It will be noted that during the season 1926–27 very little or no reduction in stand occurred on any of the alfalfa plats. During the

next year, however, there was a great mortality of plants, resulting mostly from direct winter injury. It should be noted that while many of the so-called northern varieties were injured, the greatest amount of winter injury was done to the southern types.

As a result of depletion of alfalfa stands the fields became greatly infested with grass and weeds, particularly crab grass. Fig. 1 shows the localization and intensity of the grass in 1926, one year after seeding the alfalfa. The percentages of grass and weeds in the various alfalfa varieties are given in Table 2. From these data it would appear that the inroad of grass and weeds into alfalfa fields is greatest for the so-called southern types. This may be due in part to winter injury or to a lack of aggressiveness on the part of the varieties which allows them to be overrun by grass. This lack of aggressiveness is reflected in the differences of crown and root development between various varieties.

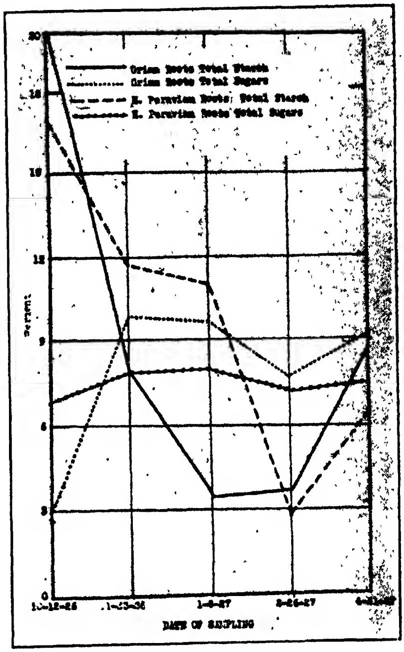

FIG. 3.—Percentages of sugar and starch in Grimm and Hairy Peruvian alfalfa during the winter months of 1926–27.

TABLE 2.—*Average percentage of crab grass in alfalfa varieties in 1927.*

| Plat No. | Variety | Alfalfa % | Grass % |
|---|---|---|---|
| 1, 16 | Utah 3332 | 35.20 | 64.90 |
| 2, 18, 21 | Grimm 565 | 62.26 | 37.74 |
| 3, 14 | Smooth Peruvian 2274 | 31.56 | 68.47 |
| 4, 17 | Argentine 2538 | 40.26 | 59.51 |
| 5, 10, 11, 13, 19 | Grimm Lyman | 74.66 | 25.34 |
| 7, 20 | Texas | 36.40 | 63.40 |
| 8 | Oklahoma | 53.50 | 46.50 |
| 9, 22 | Kansas | 62.32 | 37.68 |
| 12, 23 | Hairy Peruvian 539 | 40.02 | 59.98 |
| 15 | Baltic | 63.00 | 37.00 |

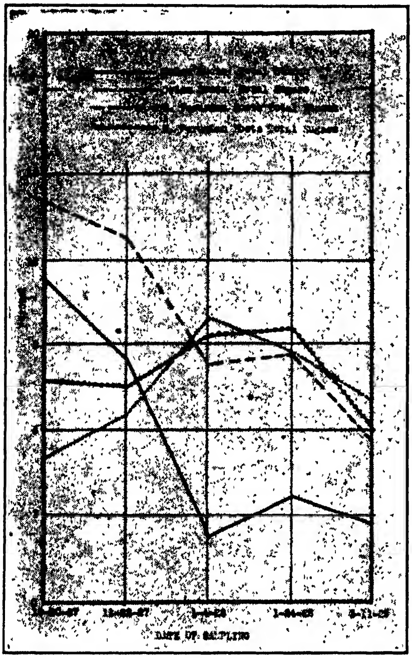

FIG. 4.—Percentages of sugar and starch in Grimm and Hairy Peuvian alfalfa during the winter months of 1927–28.

## VARIATION IN DRY MATTER AND STORAGE SUBSTANCE

Data for the changes of the carbohydrate storage substances are given in Table 3 and are shown graphically in Figs. 3 and 4. Two outstanding points are suggested in these data, namely, the high starch content in the fall of the year, and second, the conversion of this starch to sugar during the winter months. This condition prevails for both years of the test. Grimm and Hairy Peruvian alfalfa were used in this organic root reserve study, because the writer was of the opinion that the northern variety would have the greater percentage of starch reserve during the fall and winter. This opinion, however, was not borne out by the results, and it appears that other factors must be responsible for the greater longevity of the Grimm plants.

## DRY WEIGHT

The percentage dry weights, as well as total dry weight per plant, of the Grimm and Harry Peruvian varieties of alfalfa are given in Tables 4 and 5. The plant samples were not taken on specifically the same date each year, hence in order to compare the percentage of dry weight (Fig. 5) of the roots during the winter months, the sampling dates have been designated for the month in which the

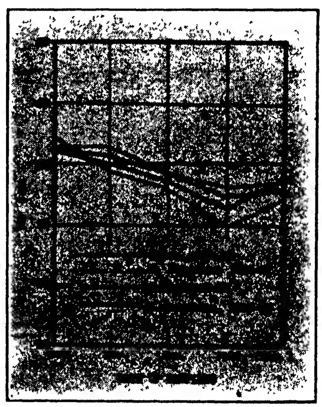

FIG. 5.—Percentage dry weight during the winter months of a hardy and non hardy variety of alfalfa.

TABLE 3.—*Changes in forms of carbohydrate in two varieties of alfalfa.*

| Variety | Date analyzed | Reducing sugars | Total sugars | Water-soluble starch | Insoluble starch | Total starch | Hemi-cellulose |
|---|---|---|---|---|---|---|---|
| | | | 1926–27 | | | | |
| | | % | % | % | % | % | % |
| Hairy Peruvian tops | Oct. 12, '26 | 0.68 | 1.64 | 0.94 | 1.18 | | 6.09 |
| | Nov. 23, '26 | 0.68 | 3.77 | 0.53 | 0.80 | | 7.90 |
| | Jan. 8, '27 | 0.49 | 3.03 | 0.66 | 1.03 | | 7.20 |
| | Feb. 26, '27 | 0.49 | 1.40 | 0.60 | 2.39 | | 8.25 |
| | April 21, '27 | 1.22 | 3.51 | 1.03 | 4.08 | | 8.88 |
| Hairy Peruvian roots | Oct. 12, '26 | 5.83 | 6.92 | 3.99 | 12.91 | 16.90 | 6.36 |
| | Nov. 23, '26 | 2.10 | 7.92 | 2.15 | 9.55 | 11.70 | 7.82 |
| | Jan. 8, '27 | 1.36 | 8.02 | 3.31 | 7.71 | 11.02 | 8.65 |
| | Feb. 26, '27 | 1.54 | 7.37 | 1.73 | 1.25 | 2.98 | 8.95 |
| | April 21, '27 | 1.61 | 7.56 | 1.82 | 4.74 | 6.56 | 9.24 |
| Grimm tops | Oct. 12, '26 | 0.15 | 0.63 | 0.56 | 2.19 | | 4.52 |
| | Nov. 23, '26 | 0.26 | 5.32 | 0.64 | 0.74 | | 7.52 |
| | Jan. 8, '27 | 0.72 | 3.25 | 0.49 | 1.43 | | 4.96 |
| | Feb. 26, '27 | 0.49 | 2.15 | 0.72 | 0.80 | | 7.59 |
| | April 21, '27 | 1.67 | 5.25 | 0.87 | 2.61 | | 7.82 |
| Grimm roots | Oct. 12, '26 | 2.11 | 3.04 | 2.19 | 17.95 | 20.14 | 7.56 |
| | Nov. 23, '26 | 1.12 | 9.87 | 1.31 | 6.70 | 8.01 | 7.18 |
| | Jan. 8, '27 | 0.45 | 9.72 | 0.72 | 2.70 | 8.79 | 7.15 |
| | Feb. 26, '27 | 1.08 | 7.71 | 1.19 | 2.27 | 3.46 | 8.50 |
| | April 21, '27 | 3.58 | 9.13 | 2.73 | 6.06 | 8.79 | 8.56 |
| | | | 1927–28 | | | | |
| Hairy Peruvian tops | Oct. 20, '27 | 2.81 | 4.32 | 1.21 | 2.08 | | 12.98 |
| | Nov. 22, '27 | 0.75 | 2.28 | 0.70 | 1.14 | | 9.88 |
| | Jan. 4, '28 | | | | | | |
| | Jan. 24, '28 | 1.01 | 1.51 | 0.50 | 0.73 | | 9.86 |
| | Mar. 11, '28 | 1.09 | 1.35 | 0.68 | 1.71 | | 11.17 |
| Hairy Peruvian roots | Oct. 20, '27 | 2.63 | 5.08 | 2.72 | 11.39 | 14.11 | 10.12 |
| | Nov. 22, '27 | 2.56 | 6.50 | 1.89 | 10.98 | 12.84 | 10.54 |
| | Jan. 4, '28 | 1.86 | 9.83 | 1.61 | 6.71 | 8.32 | 10.63 |
| | Jan. 24, '28 | 2.31 | 8.65 | 1.34 | 7.14 | 8.48 | 10.74 |
| | Mar. 11, '28 | 3.23 | 7.00 | 1.15 | 4.33 | 5.48 | 11.57 |
| Grimm tops | Oct. 20, '27 | 3.47 | 4.78 | 1.12 | 2.10 | | 12.66 |
| | Nov. 22, '27 | 0.85 | 4.33 | 0.76 | 0.98 | | 9.54 |
| | Jan. 4, '28 | | | | | | |
| | Jan. 24, '28 | 1.47 | 2.91 | 1.20 | 0.84 | | 12.61 |
| | Mar. 11, '28 | 1.40 | 1.57 | 0.96 | 1.59 | | 10.46 |
| Grimm roots | Oct. 20, '27 | 2.71 | 7.72 | 2.61 | 8.73 | 11.34 | 9.96 |
| | Nov. 22, '27 | 1.41 | 7.50 | 1.91 | 6.51 | 8.42 | 9.72 |
| | Jan. 4, '28 | 1.07 | 9.37 | 1.01 | 1.35 | 2.36 | 10.71 |
| | Jan. 24, '28 | 1.26 | 9.56 | 1.14 | 2.47 | 3.61 | 11.06 |
| | Mar. 11, '28 | 2.04 | 6.04 | 0.89 | 1.18 | 2.07 | 11.35 |

samples were collected. By using this means of comparison, it will be noted that the percentage dry weight of the roots for the Grimm variety is on the average about 2% greater than that of the Hairy Peruvian variety. It is also interesting to note that the percentage dry weight for both varieties in both years decreases during the winter and increases again towards spring.

TABLE 4.—*Dry weights of two varieties of alfalfa during 1926–27, together with the number of crown buds per plant.*

| Date | Height of top, inches | Number of crown buds | Dry weight Tops % | Dry weight Roots % | Dry weight per plant in grams Tops | Dry weight per plant in grams Roots |
|---|---|---|---|---|---|---|
| | | Grimm | | | | |
| Oct. 12, '26 | 19 | 12 | 28.04 | 42.78 | 3.06 | 5.53 |
| Nov. 23, '26 | 6 | 17 | 33.86 | 40.16 | 2.94 | 6.40 |
| Jan. 8, '27 | 2 | — | 40.00 | 37.80 | 2.24 | 4.10 |
| Feb. 26, '29 | 2 | 18 | 31.50 | 32.93 | 2.50 | 3.83 |
| April 20, '27 | 18 | 20 | 26.70 | 37.95 | 6.53 | 5.85 |
| | | Hairy Peruvian | | | | |
| Oct. 12, '26 | 24 | 4 | 21.63 | 44.64 | 2.166 | 3.450 |
| Nov. 23, '26 | 6 | 5 | 33.32 | 39.31 | 1.265 | 3.200 |
| Jan. 8, '27 | 7 | — | 44.62 | 36.29 | 2.090 | 3.400 |
| Feb. 26, '27 | 4 | 3 | 33.60 | 29.81 | 1.234 | 2.665 |
| April 20, '27 | 14 | 4 | 26.81 | 34.92 | 2.467 | 3.530 |

TABLE 5.—*Dry weights of two varieties of alfalfa during 1927–28.*

| Date | Dry weight Tops % | Dry weight Roots % | Dry weight per plant in grams Tops | Dry weight per plant in grams Roots |
|---|---|---|---|---|
| | | Grimm | | |
| Oct. 20, '27 | 33.0 | 43.0 | 5.19 | 8.17 |
| Nov. 22, '27 | 40.0 | 43.0 | 3.04 | 7.72 |
| Jan. 4, '28 | —— | 38.55 | —— | 2.56 |
| Jan. 24, '28 | 39.0 | 36.00 | 4.87 | 7.10 |
| Mar. 11, '28 | 32.5 | 37.00 | 4.51 | 6.94 |
| | | Hairy Peruvian | | |
| Oct. 20, '27 | 32.0 | 43.00 | 4.16 | 6.98 |
| Nov. 22, '27 | 40.0 | 39.00 | 2.48 | 6.63 |
| Jan. 4, '28 | —— | 38.55 | —— | 1.51 |
| Jan. 24, '28 | 47.2 | 35.00 | 1.67 | 6.03 |
| Mar. 11, '28 | 42.2 | 36.00 | 1.72 | 5.97 |

TABLE 6.—*Nitrogen distribution in Grimm and Hairy Peruvian alfalfa roots during the winter of 1926–27.*

| Date collected | Part of plant | Total nitrogen % | Water-soluble nitrogen % | Protein nitrogen % | Nitrogen in filtrate % | Total nitrogen soluble % | Soluble nitrogen precipitated % |
|---|---|---|---|---|---|---|---|
| Oct. 19, '26 | Grimm roots | 2.163 | 1.5514 | 0.4924 | 0.937 | 71.77 | 31.74 |
| Oct. 19, '26 | Grimm tops | 3.3802 | —— | —— | —— | —— | —— |
| Oct. 19, '26 | Hairy Peruvian roots | 1.819 | 1.1142 | 0.3994 | 0.835 | 61.25 | 35.85 |
| Oct. 19, '26 | Hairy Peruvian tops | 2.786 | 1.268 | 0.5286 | 0.797 | 45.51 | 41.69 |
| Dec. 17, '26 | Grimm roots | 2.08 | 1.77 | 0.623 | 1.15 | 85.5 | 35.2 |
| Dec. 17, '26 | Hairy Peruvian roots | 2.06 | 1.42 | 0.546 | 0.88 | 68.50 | 38.4 |
| Jan. 8, '27 | Grimm roots | 2.15 | 1.19 | 0.48 | 0.72 | 55.3 | 40.3 |
| Jan. 8, '27 | Hairy Peruvian roots | 2.75 | 1.33 | 0.556 | 0.76 | 48.4 | 41.7 |
| Feb. 26, '27 | Grimm roots | 2.53 | 1.47 | 0.38 | 1.09 | 58.1 | 80.1 |
| Feb. 26, '27 | Hairy Peruvian roots | 2.53 | 1.33 | 0.38 | 0.96 | 52.5 | 72.3 |

TABLE 7.—*Water-soluble nitrogen obtained in two varieties of alfalfa during the winter months of 1927–28.*

| Date collected | Tops: Total nitrogen % | Tops: Soluble nitrogen % | Roots: Total nitrogen % | Roots: Soluble nitrogen % | Total nitrogen soluble. Tops % | Total nitrogen soluble. Roots % |
|---|---|---|---|---|---|---|
| | | | Grimm | | | |
| Oct. 20, '27 | 2.947 | 0.877 | 2.08 | 0.91 | 29.6 | 43.8 |
| Nov. 22, '27 | 2.97 | 0.968 | 2.42 | 1.02 | 32.2 | 42.2 |
| Jan. 4, '28 | —— | —— | 2.44 | 1.09 | —— | 44.7 |
| Jan. 24, '28 | 2.91 | 0.981 | 2.69 | 1.203 | 33.6 | 44.6 |
| Mar. 11, '28 | 3.54 | 1.030 | 2.37 | 1.11 | 29.1 | 46.8 |
| | | | Hairy Peruvian | | | |
| Oct. 20, '27 | 2.75 | 0.840 | 2.08 | 0.82 | 30.5 | 39.4 |
| Nov. 22, '27 | 2.94 | 0.968 | 2.22 | 0.91 | 32.6 | 44.3 |
| Jan. 4, '28 | —— | —— | 2.21 | 1.04 | —— | 46.8 |
| Jan. 24, '28 | 2.31 | 0.805 | 2.18 | 0.77 | 34.9 | 35.3 |
| Mar. 11, '28 | 2.61 | 0.640 | 1.81 | 0.77 | 34.5 | 42.5 |

## NITROGEN

The total nitrogen as revealed from data in Tables 6 and 7 does not appear to play an important part from a root storage standpoint. The total nitrogen remains approximately the same throughout the winter season. The percentage of the total nitrogen that was soluble seems to be greatest (Fig. 6) for the Grimm alfalfa roots. However, the percentage coagulable of the soluble nitrogen, with the exception of the analyses made on Feb. 26, 1927, is greatest for the Hairy Peruvian roots.

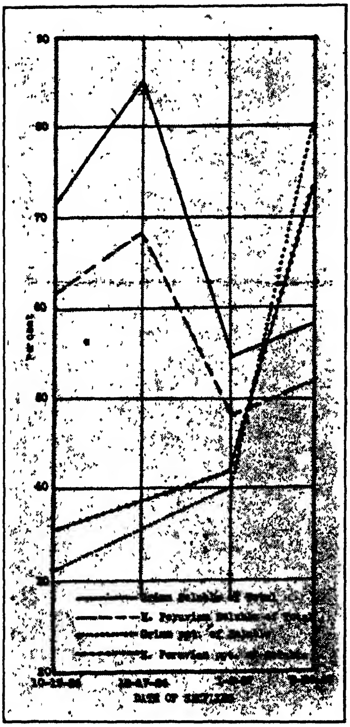

FIG. 6.—Nitrogen distribution in two varieties of alfalfa during the winter months.

The data of the total nitrogen analyses of the 1927–28 alfalfa roots are given in Table 7. It appears from these data that the percentage of total nitrogen throughout the season was greater for the Grimm variety than for the Hairy Peruvian. Very little significance can be attributed to the results from the soluble nitrogen as obtained in that year. The method used in analyzing for soluble nitrogen in 1927–28 was different, as previously noted, from that of the previous year.

## DISCUSSION

No attempt will be made in this paper to review the literature on the organic root reserves of plants. This has been well done by Throwbridge (16) and by Graber, et al (3). It is sufficient to state here that the organic reserves, including the sugars, starch, hemicellulose, and nitrogen compounds, are found to have an important bearing on the productivity and, in many cases, longevity of plants. It has been shown (3, 16, 18, 21) that organic root reserves vary with the type of treatment given the aerial part of the plant, and conversely, the amount of top growth produced by perennial plants,

particularly herbaceous plants, is partially dependent upon the organic reserves in the roots. It has been shown that the continual depletion of the organic root reserves of the plant as a result of frequent top cuttings leads to the eventual destruction of the plant. Such plants are more readily overrun by weeds (3) and more easily destroyed by winter injury.

In view of the fact that considerable trouble has been experienced with the early loss of alfalfa stands in northwest Arkansas and because these losses are correlated with the less hardy varieties as indicated by varietal field tests (Table 1), a study was made of the changes of the organic reserves of two varieties of alfalfa roots, Hairy Peruvian and Grimm during the early fall and winter months to discover if any correlation exists between these factors and reduction in plant stand.

The inroad of crab grass and weeds into alfalfa fields is a serious factor, and it appears from the data presented that this inroad takes place on the less hardy strains of alfalfa. This seems to be particularly true in the early life of the fields. When the field becomes older there is a general overrunning by weeds with little relationship to varieties. Whether this more rapid rate of inroad of weeds is due to a lack of aggressiveness on the part of the plant which would otherwise tend to crowd the grass and weeds, or whether it is due to the fact that the alfalfa plants are first killed through winter injury and disease, or both, is not clear and remains for future investigation. The aggressive nature of the alfalfa plant, however, is to a great extent dependent upon the treatment given the plants, as shown in the work of Graber, et al (3). That there is a decided difference in the type of crown development which reflects itself in the aggressive nature of the plant is shown in Fig. 7. A lack of crown development is noticeable in many of the southern varieties of alfalfa and is similar to a great extent to the type of development obtained by Graber, et al (3) in Grimm alfalfa plants as a result of frequent top cuttings. In this connection it should also be noted that there is a decided difference in root development between the so-called northern and southern alfalfa varieties. Thus, the branched type of root system is emphasized much more in the Baltic, Utah, Kansas, and Grimm varieties than in the Peruvian, Argentine, and Texas varieties. How this type of root development may modify the winterhardiness of the plant from a physical standpoint the writer is unable to say. However, it may be a factor tending towards the maintenance of stand.

In the work of Graber, et al (3), a correlation between winterhardiness of the alfalfa plant and the organic reserves of the root is

emphatically revealed. These studies would suggest a difference in the capacity of the Grimm and Hairy Peruvian plants to synthesize and store abundant root reserves preparatory to winter months, since these varieties show a marked contrast in their winterhardiness.

It will be noted from Fig. 5 that the percentage dry weight for the roots of Grimm alfalfa is greater than that of Hairy Peruvian.

FIG. 7.—Differences in crown and root development of Hairy Peruvian (left) and Grimm (right) alfalfa.

These results are in harmony with the findings of other workers (1, 5, 6, 9, 19) who have shown greater percentages of dry matter of plants correlated with winterhardiness.

The weight per plant for 1926–27 is shown in Fig. 8. It will be noted that the top dry weight fluctuates greatly. Some of this fluctuation is due to cutting, thus on Oct. 19, 1926, all varieties were harvested, making the subsequent top weight light. It is evident, however, that active growth took place in winter in the

Hairy Peruvian variety, whereas Grimm remained dormant and inactive. The light top growth of Hairy Peruvian on Feb. 26, 1927, was due to the fact that previously it had been severely frozen. The depletion of root reserves of the Grimm variety based on total dry weight began about Nov. 23, 1926 whereas, this effect is not noted in the case of the Hairy Peruvian variety. It appears, therefore, that while Grimm is lying dormant during the winter months Hairy Peruvian may frequently begin active growth and may be injured intermittently by freezing temperatures.

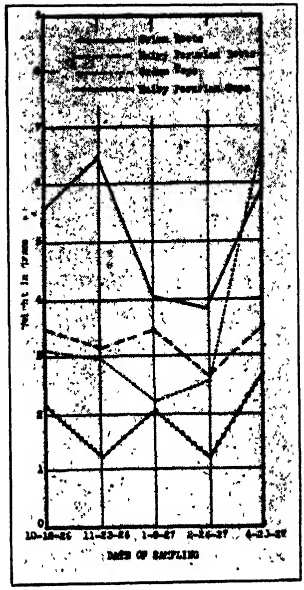

FIG. 8.—Weight in grams per plant during the winter of hardy and non-hardy alfalfa varieties.

It will be noted from Fig. 3 that the starch content of the root is high in the fall but decreases during the winter months, much of it no doubt being converted into sugars. No significant correlation can be observed with the sugars and starch and winter-hardiness, except that the sugars are higher in the Grimm variety. The 1927–28 results (Fig. 4) do not show a constant sugar percentage in the Grimm roots, although in the middle of winter the sugar is greater for this variety than in Hairy Peruvian. These data on the sugars do not appear to be of sufficient significance to account for the differences in the hardiness of the two plants. This is in agreement with the findings of other investigators (4, 15) which tend to show that sugars are not definitely correlated with winterhardiness of the plant. Yet it has also been shown that sugars may act in protecting proteins in plant sap from precipitating under low temperatures (2, 13, 14, 15).

It should be noted that in 1927–28 the starch content of the roots of Hairy Peruvian was greater than that of Grimm, yet the winter mortality was several times as great for the former as for the latter variety. Hence, it appears that from an organic storage standpoint the differences in the winterhardiness of the two plants cannot be accounted for on the basis of sugar and starch content. It was noted, however, that the early development of the plants in the

spring of 1928 was greater for Hairy Peruvian than for Grimm and continued to be greater during the entire summer, also the summer mortality of plants for Hairy Peruvian was considered less than for Grimm. From this standpoint, therefore, the abundant reserve is of fundamental importance.

The greatest percentage of total nitrogen was found in the roots of Grimm. From the data on the percentage of total nitrogen which was soluble, as well as the percentage of soluble nitrogen that was heat coagulable, for analyses made of roots in 1926–27, it will be seen that there is some correlation between the water-soluble fraction and the latent winter hardy capacity of the two varieties of plants. What importance should be placed on these relationships, the writer is unable to say.

From the results thus obtained on the storage substance of the two types of plants it is impossible to see any definite relation of these substances, either in kind or total amounts, with winterhardiness. It is evident, however, from observations made in the field, that early vigorous spring growth is directly associated with a well-developed plant and that these plants are not nearly as readily injured by disease attacks as are the poorly developed plants.

It frequently happens that a portion of the plant becomes winter-killed. This is particularly true of the Hairy Peruvian type which may resume active growth in the middle of winter. This intermittent growth made during the winter may be repeatedly set back by a severe freeze. It frequently happens that portions of the crown buds are severely injured while others escape injury. If the plant is aggressive and has a good crown system, such as Grimm, new buds will take the place of the old, but in the weaker plants this does not occur and this lack of new growth is frequently followed by fungal invasion. Even vigorous plants which become slightly frost injured may become infected with fungi, but more often they survive the attacks. No attempt has been made by the writer to isolate any of the invading organisms of the winter injured plants, though Dr. Young of the Plant Pathology Department has isolated a fusarium from injured alfalfa roots. Similar observations as noted above have been reported by Weimer (20). The symptoms which he described are very similar to the injured plants noted above, although in these plants injury is mostly localized in the crown section. (See Fig. 9.)

Jones (7) and LeClerge (10) have recently described a form of vessel plugging of the alfalfa root resulting from the action of bacterial wilt, or according to Jones (7), it may be developed by either the action of wilt organism or by frost. In either case, however, the

vessels become plugged with a gumlike substance. This plugging of the vessels interferes with the free transfer of water (10) which may cause wilting of the plant, particularly in the early spring or after cutting the plant and is said to result eventually in a stunted condition of the plant resulting in a low starch reserve.

FIG. 9.—Forms of crown injuries found in alfalfa fields. A, healthy plant; B, winter killed; C, D, E, diseased crowns.

It would appear, therefore, that the depletion of alfalfa stands cannot be attributed to any single factor, but rather that a combination of factors are responsible, among which may be mentioned a lack of winterhardiness and disease. These may be partially controlled by the choice of varieties and by proper cultural practices.

## SUMMARY

A study was made of (a) the organic root reserves, as well as the changes occurring in these reserves, in two varieties of alfalfa (hardy and non-hardy) during the winter months; (b) the relationship between the organic reserves of alfalfa roots and stand reduction; (c) relation between varieties and reduction of stand from the standpoint of the aggressive character of the plant, as revealed in crown and root development; and (d) the possible effect of winter injury and subsequent final invasion as related to well developed plants.

1. These studies indicate that there is a rapid reduction in alfalfa stand after the second year of alfalfa cropping on the same land.

2. Some varieties are more persistent in maintaining a good stand than others. Northern varieties of alfalfa seem to maintain their

stand longer than southern varieties. There is a decided difference between the root and crown systems of the two groups of alfalfa. The northern varieties seems to have a greater forked root system and to develop a larger crown system than the southern varieties.

3. Winter dormancy seems to be an essential prerequisite for any variety if it is to be grown successfully in this section. Varieties which do not resume growth readily during warm periods of the winter are desired.

4. The reduction of stand may result from direct killing by low temperatures, by freezing to death as a result of fluctuating temperatures, or by partial freezing and subsequent fungal and bacterial invasion of the crown and root system of the plant.

5. The percentage of dry weight and total dry matter per plant are greater for the Grimm winterhardy variety than for the Hairy Peruvian non-winterhardy variety.

6. It appears from a study of the carbohydrate reserves of the roots of Hairy Peruvian (southern) and Grimm (northern) alfalfa that the sugars are nearly always greater during the winter in the latter than in the former variety. This is particularly true for the middle winter period. The starch and dextrins may vary with the season and plant. This latter is apparently dependent upon the time the plants were cut in the fall. The total soluble nitrogen is greater in roots of the Grimm variety during the winter months.

7. It appears that the wide changes of temperature over a short time are more harmful here than severe cold weather. Successive warm and cold periods kill top growth of the less hardy varieties and allow for fungal invasions.

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# CORRELATIONS BETWEEN SEED EAR AND KERNEL CHARACTERS AND YIELD OF CORN[1]

ARTHUR M. BRUNSON and J. G. WILLIER[2]

Numerous investigations have been conducted on the relation between seed ear characters and productiveness in corn. Most of these have been reviewed in some detail elsewhere (2, 4)[3] and need no mention here, except to state that, in general, there seemed to be a small but consistent tendency for those ears which are heavier and longer and which have fewer rows, smoother indentation, and lower shelling percentages to produce the larger yields.[4] The suggestion was made (3) that part of this apparent relation between yield and ear characters might be a reflection of one between yield and kernel characters, and, if so, kernel characters might have some bearing on the kind of seed ears desirable for planting. A fairly extensive ear-row planting of Pride of Saline corn was made for other purposes at the Kansas Agricultural Experiment Station. Accordingly, it seemed worth while to measure some of the kernel characters, as well as ear characters, and to determine the relation to yield. These studies are herein reported.

## MATERIALS AND METHODS

In the fall of 1923 about 1,000 seed ears were picked from the standing stalks in a field of certified Pride of Saline corn on the Agronomy Farm. During the following winter, individual ear germination tests were made. On the basis of these tests and the soundness of the ears, 900 were finally selected for planting. Due to the method of selection and number of ears it was thought these 900 ears represented a very fair sample of Pride of Saline suitable for seed.

### EAR AND KERNEL MEASUREMENTS

Ear and kernel measurements were made in centimeters or millimeters. Ear circumference and cob circumference were taken at

[1]Joint contribution from office of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture and the Kansas Agricultural Experiment Station, Manhattan, Kan. Contribution No. 182 of the Agronomy Department, Kansas Agricultural Experiment Station. Received for publication April 5, 1929.

[2]Agronomist and formerly Assistant Agronomist in Corn Investigations, respectively.

[3]Reference by number is to "Literature Cited," p. 922.

[4]The following publication reporting similar studies has come to the attention of the authors since submitting this manuscript: HUGHES, H. D., and ROBINSON, J. L., Relation of certain ear and kernel characters of Reid Yellow Dent corn to yield. Iowa Agr. Exp. Sta. Bul. 257. 1929.

one-third of the distance from the butt to the tip. Kernel length, kernel breadth, and kernel thickness for a given ear were measured on 10 representative kernels placed in a groove. Indentation and angularity were estimated by comparing each ear with standard samples representing the range of variation and designated numerically from one to six for indentation and from one to five for angularity. Of the six grades for indentation, grade 1 designated the very smooth or flinty type and grade 6 designated the rough extreme. Of the five grades for angularity, grade 1 designated sharp shouldered kernels, whereas grade 5 designated kernels with very rounded sides resulting in wide spaces at the crown between the kernel rows.

## EAR ROW PLATS

These 900 ears were compared for productiveness in 1924 and again in 1925 by planting in ear rows. The ear rows were 10 hills long, planted two kernels per hill by hand, and were not thinned. Check rows from a bulk sample of good seed of the same variety were planted as every tenth row. Each year the rows were planted in triplicate and the sum of the six rows from each ear was taken as the yield representing that ear. The land used in these experiments was level and of more than average uniformity.

Harvesting and weighing were done in November at which time the ears were uniformly mature and dry. It was thought that little if any error would be introduced by using field weights and hence no shrinkage samples were taken. Prolificacy was computed as the number of ears per row divided by the number of plants per row.

## VARIABLES

The variables considered, together with their symbols, are shown in Table 1. The means and standard deviations are included as a

TABLE 1.—*Variables considered, symbols used, means, and standard deviations.*

| Symbol | Variable | Mean | Standard deviation |
|---|---|---|---|
| E | Ear length, cm | 22.86±.041 | 1.84±.029 |
| D | Ear circumference, mm | 168.52±.218 | 9.70±.154 |
| C | Cob circumference, mm | 108.54±.194 | 8.63±.137 |
| R | Rows of kernels | 14.71±.039 | 1.72±.027 |
| I | Indentation | 2.63±.019 | 0.85±.014 |
| A | Angularity | 2.54±.023 | 1.03±.016 |
| W | Weight of 100 kernels, grams | 41.21±.101 | 4.50±.072 |
| L | Kernel length, mm | 13.05±.017 | 0.75±.012 |
| B | Kernel breadth, mm | 9.87±.016 | 0.73±.012 |
| T | Kernel thickness, mm | 4.22±.007 | 0.29±.005 |
| Y | Yield, pounds | 69.34±.244 | 10.86±.173 |
| P | Prolificacy | 1.12±.003 | 0.14±.002 |
| S | Stand | 104.44±.205 | 9.11±.145 |

matter of record. The first 10 variables are ear or kernel characters of which measurements were taken before planting. The last three variables represent field data and are totals (yield and stand) or averages (prolificacy) of the data for 1924 and 1925. Both seasons were favorable for corn and yields were very similar in the two years.

The computations were all made to six decimal places. Coefficients of correlation are reported only to three decimal places.

The correlations are considered in four groups for convenience. As in other studies of a similar nature the coefficients of correlation between seed ear characters and yield are small. This is probably due to the fact that a considerable part of the variation in yield is due to causes other than heritable differences, as pointed out by Richey and Willier (3). They estimate that in their experiments only about 10% of the variation in yield was due to genetic differences. Thus, the large amount of random variation tends partially to mask relations between ear type and yield and makes it possible to place considerable confidence in correlations which would otherwise be considered too small to be of value for predictive purposes. Most of the distributions for the various characters closely approached the normal frequency curve. The distribution for stand (number of plants per row) deviated most from normalcy, but even here the skewness was not pronounced. None of the regressions depart sufficiently from a straight line to be considered curvilinear.

## CORRELATIONS

### EAR AND KERNEL CHARACTERS

Coefficients of correlation among the various ear and kernel characters are shown in Table 2. Inasmuch as somewhat similar studies of the interrelation of ear characters have been made, it seems desirable to mention only a few of the relationships, principally those involving kernel characters.

Number of rows is significantly correlated with all other characters considered. The condition of many rows was associated with short thick ears with little space between rows and with rough, light kernels which are very narrow but comparatively long and thick.

Ears with roughly indented kernels were, in general, short and thick with many rows and narrow row spaces. Kernels on these ears tended to be long and thin, but there was little relation between kernel weight or kernel breadth and indentation.

Wide spaces between rows (rounded kernels) were found more frequently in slender ears with few rows of smooth, heavy kernels which tended to be short and broad. Ear length and kernel thickness had little relation to kernel angularity.

TABLE 2.—*Coefficients of correlation among ear and kernel characters.*

| Symbol | Variable | Coefficients of correlation between the variables designated in the column headings below and the variable in column 2* | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | E | D | C | R | I | A | W | L | B | T |
| | | Ear length | Ear circumference | Cob circumference | Rows of kernels | Indentation | Angularity | Weight of 100 kernels | Kernel length | Kernel breadth | Kernel thickness |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| E | Ear length | —— | —0.022 | 0.055 | *—0.072* | *—0.103* | 0.051 | *0.286* | *—0.103* | *0.114* | *0.302* |
| D | Ear circumference | —0.022 | —— | *0.799* | *0.570* | *0.237* | *—0.258* | *0.189* | *0.383* | —0.058 | *0.105* |
| C | Cob circumference | 0.055 | *0.799* | —— | *0.507* | 0.017 | *—0.158* | *0.099* | —0.058 | —0.013 | *0.222* |
| R | Rows of kernels | *—0.072* | *0.570* | *0.507* | —— | *0.116* | *—0.484* | *—0.367* | *0.180* | *—0.728* | *0.094* |
| I | Indentation | *—0.103* | *0.237* | 0.017 | *0.116* | —— | *—0.251* | —0.006 | *0.391* | —0.031 | *—0.192* |
| A | Angularity | 0.051 | *—0.258* | *—0.158* | *—0.484* | *—0.251* | —— | *0.218* | *—0.153* | *0.305* | —0.001 |
| W | Weight of 100 kernels | *0.286* | *0.189* | *0.099* | *—0.367* | —0.006 | *0.218* | —— | *0.219* | *0.614* | *0.480* |
| L | Kernel length | *—0.103* | *0.383* | —0.058 | *0.180* | *0.391* | *—0.153* | *0.219* | —— | —0.039 | *—0.162* |
| B | Kernel breadth | *0.114* | —0.058 | —0.013 | *—0.728* | —0.031 | *0.305* | *0.614* | —0.039 | —— | *0.096* |
| T | Kernel thickness | *0.302* | *0.105* | *0.222* | *0.094* | *—0.192* | —0.001 | *0.480* | *—0.162* | *0.096* | —— |

*Correlations of 0.067 are three times their probable error, those of 0.111 are five times their probable error, and those of 0.215 are ten times their probable error. Italicized values are three or more times their probable error.

Heavy kernels were associated with long, thick ears and with few widely spaced rows of long, broad, and thick kernels. Indentation was practically uncorrelated with kernel weight.

Long kernels were found more frequently on short thick ears with many rows of roughly indented, heavy, thin kernels and with narrow spaces between kernel rows.

In contrast, broad kernels were found more frequently on long ears with few rows of heavy, thick kernels and with wide spaces between kernel rows. The coefficient of correlation of kernel breadth with kernel weight and with kernel rows is especially high.

Thick kernels were found more frequently on long, thick ears with many rows of smooth, heavy, short, broad kernels.

## PROLIFICACY AND STAND WITH EAR AND KERNEL CHARACTERS

Of the three progeny characters which were studied, yield, prolificacy, and stand, yield will be considered subsequently by itself as of particular importance. This section considers the relation of the seed ear characters with prolificacy and stand of the progeny rows. The coefficients of correlation are given in Table 3.

The more prolific plants were associated with short, smooth seed ears and especially with seed ears of small circumference, having few rows of small, short, thin, and probably narrow kernels. These relations are in agreement with the commonly observed fact that large, rough types are preponderantly single eared.

In measuring prolificacy as the total number of ears per row divided by the total number of plants per row we have only the average number of ears per plant. In nearly all of the rows this value was one or above. It is impossible, unfortunately, to analyze further the variation in this character as being due to variation in number of barren plants, or variation in number of two-eared plants, or both. Not only may the smaller, more slender ears be more likely to produce two-eared plants, but they may be less likely to produce barren plants. In certain southern varieties, Kyle and Stoneberg (1, page 98) have observed that, ". . . the seed from the many rowed ears produced more barren plants."

In planting the ear rows for this experiment, great care was exercised to obtain an accurate drop, but the rows purposely were not thinned in order to measure the possible relation between seed characters and effective stand. The coefficients of correlation indicate that heavy, rounded kernels with smooth indentation had the greatest survival value. This suggests one possible reason why smooth or medium types of indentation have usually outyielded the extremely rough types of corn in experiments not thinned to a uniform stand.

TABLE 3.—*Coefficients of correlation for prolificacy and stand with ear and kernel characters.*

| Symbol | Variable | Coefficients of correlation between the variables designated in the column headings below and the variable in column 2* | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | E | D | C | R | I | A | W | L | B | T |
| | | Ear length | Ear circumference | Cob circumference | Rows of kernels | Indentation | Angularity | Weight of 100 kernels | Kernel length | Kernel breadth | Kernel thickness |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| P | Prolificacy (ears per plant) | *—0.093* | *—0.288* | *—0.299* | *—0.142* | *—0.087* | 0.036 | *—0.101* | *—0.070* | —0.065 | *—0.107* |
| S | Stand (plants per row) | 0.032 | —0.003 | —0.011 | —0.049 | *—0.182* | *0.086* | *0.139* | —0.023 | 0.014 | 0.041 |

*Correlations of 0.067 are three times their probable error, those of 0.111 are five times their probable error, and those of 0.215 are ten times their probable error. Italicized values are three or more times their probable error.

## YIELD, STAND, AND PROLIFICACY

Coefficients of correlation among the three progeny characters of yield, stand, and prolificacy are shown in Table 4. It seems likely that some of the concomitancy in the variation of these characters is the result of variation in environment, while some may be due to inherited differences of the various ear rows. To take a case in point, the more prolific rows tended to be higher yielding. The question at once arises whether prolific strains are inherently higher yielding, or whether the rows growing on the better portions of the field produced both higher yields and more ears per plant due to favorable growing conditions. In order to compare the association of these variables in the ear rows with that in the check rows, the corresponding correlations for the latter group were calculated and are shown in the last column of Table 4. In the check rows only 100 observations were available for each character, each observation being the mean or sum of the values from six corresponding rows covering the two years of the experiment. It is obvious that similar comparisons of correlations in the check rows could not be made where the correlations involved ear or kernel characters inasmuch as the check rows were planted with a composite lot of seed.

TABLE 4.—*Coefficients of correlation among yield prolificacy and stand.*

| Characters correlated | Coefficients of correlation | |
|---|---|---|
| | Ear rows | Check rows |
| Yield and prolificacy | 0.554±.016 | 0.340±.060 |
| Yield and stand | 0.580±.015 | 0.337±.060 |
| Prolificacy and stand | 0.002±.023 | —0.233±.064 |

In the ear rows, yield was correlated highly and positively with prolificacy. In the check rows, the corresponding coefficient was somewhat lower, but still highly significant. In the check rows we can assume that differences in productivity due to seed were random, and that in the main such differences in productivity were due to variation in environment, principally soil heterogeneity. Thus, the correlation between yield and prolificacy in the check rows gives a measure of the degree to which variations in yield and prolificacy are concomitant when growing conditions are altered. These same influences are operative in the ear rows, together with the added effect of variation in the inheritance of the individual seed ears. The difference between the degrees of association in these two groups should give the net concomitant tendency between prolificacy and yield due to inherited differences. The coefficient of correlation between yield and prolificacy is 0.554 for the ear rows and 0.340 for the check rows (Table 4). The concomitant variation as measured

by variance would thus be 0.307 ($0.554^2$) and 0.116 ($0.340^2$), respectively, or nearly three times as great in the ear rows as in the check rows. It seems safe to assume, therefore, that in addition to the concomitant variation between yield and prolificacy due to changes in environment a positive and significant correlation exists between prolificacy and yield due entirely to differences in inheritance, or stated in other words, those strains which tend to have multiple eared plants are in general the higher yielding.

Prolificacy and stand were uncorrelated in the ear rows but were correlated significantly and negatively in the check rows. Apparently the tendency for poor stands to be compensated by larger numbers of ears per plant existing among the check rows, either did not occur among the ear rows or was obscured by other tendencies.

## YIELD WITH EAR AND KERNEL CHARACTERS

Because of their practical bearing on seed selection and crop improvement, relations between seed characters and yield of crop are always of interest. The coefficients of correlation showing these relations in the present study are presented in Table 5. As an aid in analyzing contributory causes, the partial correlations, with the effects of variation in prolificacy and in stand eliminated ("held constant"), also are included.

In this experiment yield was not significantly correlated with the length of the seed ear. When prolificacy is held constant, the coefficient of partial correlation approaches significance, indicating that if the long seed ears had tended to produce as many ears per plant as the shorter seed ears they might have been higher yielding than the shorter ears.

Yield was correlated negatively with ear circumference, cob circumference, and number of kernel rows, although only the correlation with kernel rows is significant. All three of these are changed to positive correlations, two of them significant, when prolificacy is held constant. This indicates that, were it not for the reduction in the number of ears on the progeny plants accompanying an increase in circumference of seed ear, the larger seed ears might have been the more productive.

Indentation and yield were significantly and negatively correlated, or, stated differently, rough seed ears tended to produce lower yields. Part of this effect probably was due to the poorer stands obtained from the rougher ears ($r_{sI} = -0.182$, Table 3), but the partial correlation coefficient between yield and indentation with the effect of variability in stand eliminated is still $-0.065$, or very nearly three times its probable error.

TABLE 5.—*Coefficients of correlation of yield with ear and kernel characters.*

| | Coefficients of correlation between yield and the variables designated in column headings below* | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | E<br>Ear length | D<br>Ear circumference | C<br>Cob circumference | R<br>Rows of kernels | I<br>Indentation | A<br>Angularity | W<br>Weight of 100 kernels | L<br>Kernel length | B<br>Kernel breadth | T<br>Kernel thickness |
| Gross correlations with yield | 0.001 | —0.056 | *—0.074* | —0.050 | *—0.157* | 0.030 | *0.084* | —0.028 | —0.001 | 0.023 |
| Partial correlation with yield; effect of variability due to prolificacy eliminated | 0.063 | *0.130* | *0.116* | 0.035 | *—0.132* | 0.012 | *0.169* | 0.013 | 0.043 | *0.099* |
| Partial correlation with yield; effect of variability due to stand eliminated | —0.022 | *—0.067* | *—0.083* | —0.027 | —0.065 | —0.025 | 0.004 | —0.018 | —0.011 | —0.001 |

*Both gross and partial coefficients of 0.067 are three times their probable error. Italicized values are three or more times their probable error.

Angularity had little or no association with yield as measured by either the gross or partial correlations.

Weight of kernel and yield were positively and significantly correlated. When prolificacy is held constant the coefficient of partial correlation becomes twice as large, indicating that there would be an even greater tendency for large kernels to produce large yields were it not for the compensating tendency for large kernels to produce non-prolific plants ($r_{PW}=-0.101$, Table 3). When the effect of variability in stand is eliminated, however, the coefficient of partial correlation is almost zero. Even more than in the case of indentation, the beneficial effect of large seed on yield seems to be a secondary effect of changes in stand.

The three kernel measurements of length, breadth, and thickness were practically uncorrelated with yield as shown by the gross correlation. Of the corresponding partial correlations only one, that of yield and kernel thickness with prolificacy held constant, reaches significant proportions. The fact that kernel weight was significantly correlated with yield, whereas the three elements of kernel size were practically uncorrelated with yield presents the interesting possibility that kernel density or specific gravity may have had an important relation to yield. In support of this hypothesis $r_{YW.BLT}$ was found to be 0.140. Thus, the correlation between yield and weight of kernel with the three elements of size (length, breadth, and thickness) held constant is nearly twice as much as the gross correlation between yield and weight of kernel. Corn growers have long held that a seed ear which weighs heavy for its size is desirable. If specific gravity of kernels and of ear are correlated, as they undoubtedly are, these results tend to confirm this opinion and indicate that high specific gravity of seed is correlated with productiveness.

## SUMMARY


1. Smaller seed ears tended to give progeny rows having a higher average number of ears per plant.

2. Relatively smooth indentation and small kernels of the seed ear are associated with prolificacy in the progeny.

3. Smoothly indented, heavy kernels with rounded corners are associated with high survival in the progeny plants.

4. Yield and prolificacy are highly correlated. At least part of this correlation in the ear rows seems due to the tendency of the inherently prolific strains to be the more productive.

5. Slender seed ears with smoothly indented, heavy kernels tended to produce high yielding progeny rows. The influence of circumference

of ear on yield appears to be due to its association with prolificacy, as the correlation is reversed in the partial with prolificacy held constant. The influence of weight of kernel seems to be due largely to the greater survival of plants from large kernels.

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# THE STIMULATING EFFECT OF EXTERNAL APPLICATIONS OF COPPER AND MANGANESE ON CERTAIN CHLOROTIC PLANTS OF THE FLORIDA EVERGLADES SOILS[1]

O. C. BRYAN[2]

The successful growth of agricultural crops on raw peat soils has been a difficult problem for many dacades. This was one of the outstanding problems confronting the Florida Everglades Experiment Station immediately upon its establishment in 1923. At that time poor plant growth was rather general on the Experiment Station soils, as well as on other raw peat soils of the Everglades.

The first indication of a corrective for this poor plant growth was obtained in the summer of 1925. This work was enlarged and published by Allison, *et al* (1),[3] in 1927. The results show in a remarkable way the stimulating influence of copper and manganese sulfates on the peat soils of the Florida Everglades.

The exact nature of the stimulating action of these chemicals was unknown. However, several hypotheses seemed plausible. The most important of these were as follows: (a) Fungicidal action on harmful soil organisms, (b) specific effect of the chemicals on soil toxins, and (c) nutritive effect.

Since field trials showed that 20 to 30 pounds of copper sulfate ($CuSO_4.5H_2O$) per acre produced normal plant growth, the assumption concerning the fungicidal action seemed to be untenable, particularly in a medium of as high absorptive capacity as the soil in question. The counteracting effect of the chemicals on soil toxins also seemed untenable in view of the fact that appreciable amounts of soil toxins could not be isolated. However, the nutritive effect appeared more or less plausible in the light of recent investigations (7, 11) concerning the effect of copper, manganese, etc., on plant and animal life.

On the assumption that a portion of all soluble soil constituents pass into the growing plant, the increased amount of copper or manganese in plants grown on soils treated with these elements over that contained in plants grown on non-treated soils would not

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[3]Reference by number is to "Literature Cited," p. 932.

necessarily prove the plant needs for these elements. Consequently, a study of the plant responses to copper and manganese applied to the unhealthy leaves seemed to be a more reliable and direct measure of the nutritive effect than plant analysis, particularly where only small amounts are needed.

The object of this study was to compare the stimulating action of copper and manganese sulfates applied to the leaves of the plants with that of these sulfates applied to the raw peat soil on which the plants were growing. It was thought advisable to include manganese in this study since it also produced stimulating effects on the peat soils of the Florida Everglades (1). However, its nutritive relation had recently been reported by Schreiner (11) and others, but the nutritive value of copper has never been definitely established, although some experimental work indicates as much (7).

Many years before Liebig advanced his mineral theory, plant chemists knew that the ash of plants contained small amounts of copper, manganese, and other elements (8, 9), although their nutritive value had not been established. Hence, their presence was considered more or less non-essential inasmuch as they were generally found in most soils. But the more refined chemical methods within recent years have enabled investigators to study the function of the supposedly non-essential elements on the growth of plants. The results of the more recent work show that plants require more than the 10 elements originally claimed by the early physiologists. Furthermore, copper sprays (3, 10) have for many years been suspected of producing beneficial effects, other than fungicidal, on the growth of plants.

No attempt is made to discuss the literature dealing with the nutritive effect of copper and manganese, except as it bears directly on the results of this study.

## EXPERIMENTAL WORK

About 200 pounds of the raw peat soil on which agricultural plants made poor growth were brought to the greenhouse of the College of Agriculture at Gainesville, mixed, and placed in 2-gallon jars (8 kilos of wet soil per jar). The soils in four of the jars were treated with copper sulfate at the rate of 50 pounds per acre and four were left untreated. Cowpeas and sorghum, both being very sensitive to the abnormal conditions of this soil, were planted in two jars each of both the copper-treated and untreated soils. When the seed had germinated and the plants in the untreated soils began to show unhealthy symptoms, dilute solutions, 50 p.p.m. of copper and manganese sulfates, were applied separately to the leaves of certain

plants in both the untreated and treated soils, while some plants in the same soils were left as controls. The sulfates were used because

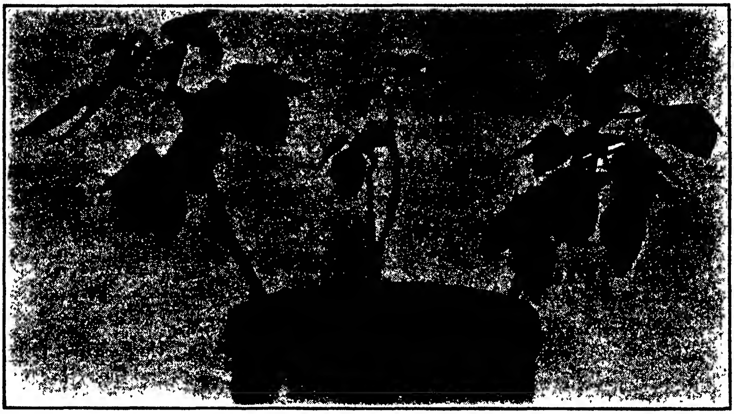

FIG. 1.—Effect of external applications of copper and manganese on cowpeas growing on untreated raw peat soil. (1) Leaves treated with a solution of manganese sulfate, 50 p.p.m.; (2) untreated; and (3) leaves treated with a solution of copper sulfate, 50 p.p.m. All plants were similar when the chemicals were applied.

no stimulation from sulfate fertilizers had been observed in the field. All the plants in any one soil were uniform in size and color when the chemicals were applied.

FIG. 2.—Effect of external applications of copper and manganese on cowpeas growing on copper-treated peat (50 pounds per acre). (1) Treated with a solution of manganese sulfate, 50 p.p.m.; (2) untreated; and (3) leaves treated with a solution of copper sulfate, 50 p.p.m.

The chemicals were applied by moistening the finger tips in the respective solutions and rubbing them over the leaves, being careful that none of the solutions came in contact with the soil in which the plants were growing. This treatment was made once a week for three weeks in succession to the treated plants, while the untreated ones were left as controls in both the copper-treated and untreated soils. All of the soils received distilled water as needed, but none was allowed to come in contact with the leaves of the treated plants. This was to avoid washing the chemicals from the leaves down to the soil. At the end of six weeks the plants were photographed just as they grew in the respective soils. Figs. 1, 2, and 3 show the


FIG. 3.—The influence of external applications of copper and manganese on the growth of sorghum in copper-treated (1) and in untreated (2) peat soils. A, leaves of plants in both soils treated with a solution of manganese sulfate, 50 p.p.m.; B, with solution of copper sulfate, 50 p.p.m.; and C, untreated.

relative responses of the plants to the different treatments. It may be seen from the figures that the chemicals were more effective when applied to the soil than when applied to the leaves, particularly in the case of sorghum. However, either method produced normal plants, whereas, in the absence of these chemicals, plant growth was poor.

Cowpea and bean seeds were planted in another series of untreated soils. When the seed had germinated and the seedlings had begun to show unhealthy symptoms—with some of the leaves dying and falling off—solutions of copper and manganese sulfate were applied to portions of the unhealthy leaves, as well as to the stems from which

the leaves had fallen. Examination of the unhealthy plants failed to reveal the presence of disease-forming organisms. The response of the treated plants to copper and manganese was very noticeable indeed. Indications of the recovery could be seen with seven to ten days after the solutions had been applied.

Figs. 4, 5, and 6 show the effect of the copper and manganese treatments on the chlorotic and unhealthy leaves. Fig. 7 shows the new leaf development of cowpeas to which copper and manganese solutions had been applied to the stems. The darkened areas (green color) on the leaves indicate where the chemicals were applied. Green color following the treatment was always associated with increased growth.

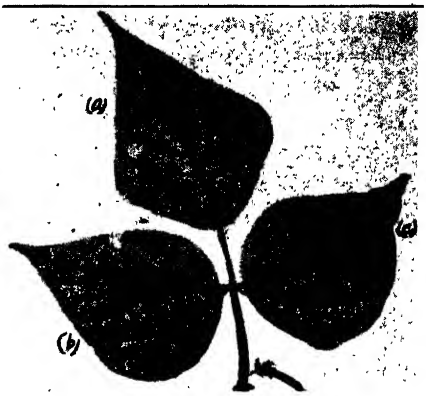

FIG. 4.—Effect of external applications of copper sulfate on the development of green color in chlorotic bean leaflets. Leaflet A received no treatment; B, one application of copper solution, 50 p.p.m.; and C, two applications. All the leaflets were similar in color when the solution was first applied. Photograph made seven days after treatment.

In another experiment the residual effect of copper on these raw peat soils was studied. Fourteen 2-gallon jars of the soil were placed in the greenhouse and treated in duplicate as follows:

| Soil No. | Treatment |
|---|---|
| 1 and 8 | Nothing |
| 2 and 9 | 75 pounds copper sulfate per acre |
| 3 and 10 | 150 pounds copper sulfate per acre |
| 4 and 11 | 250 pounds copper sulfate per acre |
| 5 and 12 | 150 pounds copper chloride per acre |
| 6 and 13 | 150 pounds sodium chloride per acre |
| 7 and 14 | 150 pounds sulfur (flowers) per acre |

The soils were then planted to sorghum and followed by cowpeas in rotation. These cultures received only distilled water as needed, except those in jars 3, 10, 5, and 12, which received additional amounts of copper before the planting of each succeeding crop. The soils were allowed to air dry at the end of the first crop of cowpeas. None of the plant residues were returned to the soil.

Fig. 8A shows the response of the first crop of sorghum to the different treatments, while Fig. 8B shows the response of the fifth crop grown on these soils (three crops of sorghum and two crops of

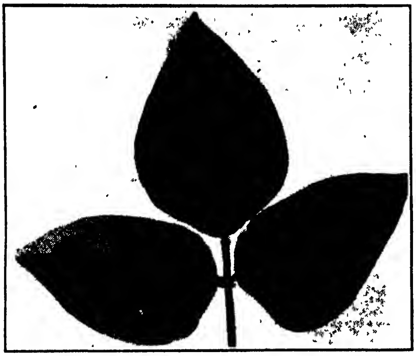

Fig. 5.—Effect of local treatments of manganese sulfate (50 p.p.m.) on the development of green color in chlorotic cowpea leaves. The dark areas show the green color where the manganese solution was applied.

cowpeas). The time used for the five crops was 22 months. The succeeding applications of copper had no apparent stimulating effect over the original copper treatment. The stimulating effect seemed to decrease in each succeeding crop, while at the same time the productivity of the untreated and the sodium chloride treated soils steadily increased until by the fifth crop they were almost as good as the copper-treated soils. It is interesting to note the stimulating action of sulfur on this soil. However, this stimulation was not as great as that of copper. Duplicates agreed in all cases.

Since the plant responses to the copper and manganese were so remarkable in both the greenhouse and field, it was thought advisable to determine the content of these elements in the untreated soil and in representative plants grown thereon. The plants grown under greenhouse conditions did not supply enough material for analysis. Consequently the analyses were made from field plants secured from copper-treated and untreated areas near the locality from which the greenhouse soils were obtained.

The copper was determined by the colorimetric ferrocyanide method and the manganese by the colorimetric permanganic acid method. Both of these methods are standard and are described in Scott's standard methods for chemical analysis. The results are given in Tables 1 and 2.


Fig. 6.—Effect of local treatments of copper sulfate (50.p.p.m.) on the development of green color in chlorotic bean leaflets. The dark areas (a, b, and c) indicate where the copper solution was applied.

TABLE 1.—*Milligrams of copper and manganese per kilo of moisture-free Everglades soils.*

| Soil No. | Location of soil | Plant responses on soil | Mgm per kilo Cu | Mgm per kilo Mn |
|---|---|---|---|---|
| 1 | Everglades Exp. Sta. | poor | 2.0 | 190 |
| 2 | Brown property, Hillsboro Canal | poor | 4.0 | 260 |
| 3 | Hialeah | poor | 3.5 | trace |
| 4 | Belle Glade | poor | trace | 160 |

TABLE 2.—*Milligrams of copper and manganese per kilo of moisture-free corn and peanut plants grown in Everglade soil.*

| Type of plant | Treatment of soil | Mgm per kilo Cu | Mgm per kilo Mn |
|---|---|---|---|
| Peanut | Copper treated | 4.5 | 29 |
| Corn | Copper treated | 7.0 | not determined |
| Peanut | Untreated soil | trace | trace |
| Corn | Untreated soil | 0.7 | not determined |

The plants on the untreated soil made very little growth, while those on the treated soil made very good growth. Furthermore, the plants grown on the copper-treated soil contained appreciable amounts of copper, while those on the untreated soil had only traces.

FIG. 7.—The development of new growth on cowpeas grown on peat soil following an application of copper and manganese (50 p.p.m.) to the stems of the depleted plants. The first leaves had practically all fallen off before the solutions were applied. (1) untreated; (2) received manganese sulfate; and (3) received copper snlfate. 50 p.p.m. Photograph made 12 days after the application of chemicals.

DISCUSSION

The results herein reported seem to show in a positive manner the fundamental action of copper and manganese on the growth of cowpeas, beans, and sorghum on the raw peat soils of the Florida Everglades. Similar results would no doubt have been obtained with other plants, since a large group of cultivated crops responded favorably to copper and manganese treatments under field conditions (1). Moreover, greenhouse results were very similar to the field results. The fact that the plant responses were almost as good where the chemicals were applied to the leaves as where they were applied to the soil indicates that these elements have a vital function in the growth of the plants.

It is doubtful that leaf treatments counteracted toxins arising from the soil. This seems to indicate a nutritive relation of these elements and tends to disprove the assumption concerning the fungicidal effect of copper on the soil organisms. Furthermore, the analyses of corn and peanut plants grown on copper-treated and on untreated soils seems to confirm these results. However, the correlation between

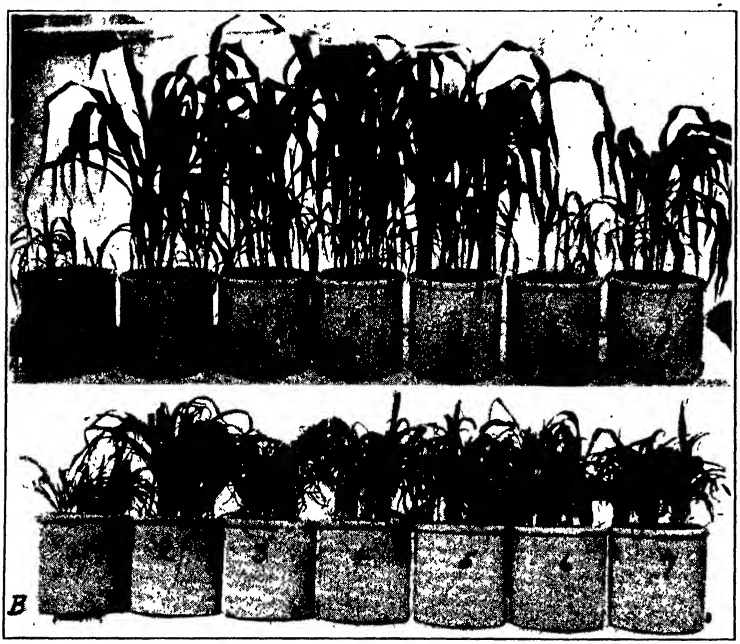


FIG. 8.—Residual effect of copper on the peat soil of the Florida Everglades. A, first crop produced with treatments given below; B, fifth crop produced with initial treatments, except pots 3 and 5 which received additional amounts of copper for each crop. Treatments per pot as follows: 1, control; 2, copper sulfate, 75 pounds per acre; 3, copper sulfate, 150 pounds per acre; 4, copper sulfate, 250 pounds per acre; 5, copper chloride, 150 pounds per acre; 6, sodium chloride, 150 pounds per acre; and 7, sulfur, 150 pounds per acre.

growth and high copper analysis does not necessarily prove the nutritive value of this element, assuming that soluble copper passes into the plant regardless of its needs.

The high content of calcium carbonate in the peat soils of the Florida Everglades (12) would perhaps lower the availability of both copper and manganese, as has been reported for iron in other soils by Gile (4). This, together with the low content and perhaps absence of these elements in places, possibly accounts for the poor plant growth on these soils. From this it would seem that the stimulating

action of sulfur was explained by its oxidation and consequent solvent effect on the copper, manganese, and other compounds in the soil, or to impurities, since sulfur is readily oxidized in these soils. Furthermore, it is common knowledge among the farmers that weathering or aeration of the raw peat soils of the Florida Everglades increases their productivity. The weathering and aeration probably increased the solubility of all the soil constituents, including copper and manganese. Assuming that the plants require only traces of copper for nutritive purposes, the original application under greenhouse conditions carried enough copper for several crops, or until that in the soil could become available, hence the lack of response from succeeding applications.

The stimulating action of both copper and manganese seemed to be closely associated with chlorophyll development, as indicated by an increase in green color soon after the application of the chemicals. Inasmuch as either one or both of the elements produced apparently healthy and mature plants, while the untreated ones failed entirely, it seems that the influence of these elements may be interchangeable and also catalytic in nature. However, the combined effects seemed to be greater than either one under field conditions (1). This would tend to show that both elements are essential.

The green coloration, presumably an increase in chlorophyll, was produced within 10 days after treatment. This was directly associated with the increased growth of the plant. On the other hand, Ruth (10) was unable to associate increased growth with an increase in chlorophyll development in beans following an application of bordeaux mixture. Beneficial effects of external applications of chemicals have been reported by other workers. Calcium-induced chlorosis of spinach was corrected by external application of manganese, according to Gilbert and McLean (5). In other instances, external treatments of iron have corrected calcium-induced chlorosis of pineapple (4).

It is interesting to note that those plants receiving copper and manganese produced mature seed, while the untreated ones failed entirely. Furthermore, applications of copper and manganese to local areas of unhealthy leaves (Figs. 4, 5, and 6) indicate a vital influence of these chemicals on the plant. This is further substantiated by the production of new growth on the old and depleted plants following treatments with copper and manganese (Fig. 7). It is true that the leaf treatments were not quite as effective as the soil treatments, but this would be expected assuming that only small amounts of the chemicals would enter the plants through the leaves and stems.

These elements appear to have a definite and positive effect on the

plant that could not be substituted by iron. According to Rose (12), the peat soils of the Florida Everglades contain a very high content of iron (1.5 to 10% $Fe_2O_3$) for organic soils. Since the stimulations were so remarkable, it seems more proper to refer to the effect of these elements as nutritive rather than catalytic. The results show that the stimulating action of copper sprays in the Everglades and elsewhere might be due in many cases to the catalytic or nutritive effect on the plant as well as to a fungicidal effect.

It is interesting to note that man has always prized sea foods. This is probably explained by the fact that the sea contains 30 or more chemical elements, including copper, manganese, and zinc, and others which probably contribute to life processes. These elements usually find their way to the sea through the leaching processes of the soil. It is very probable that a large number, if not all, soluble soil constituents contribute toward the vital processes of both plant and animal life. Only within recent years have iodine, zinc, boron, silicon, chlorine, fluorine, manganese, lithium, sodium, and others been claimed to have a vital influence on life, although the needed amounts may be very small.

Until recent years copper has been considered almost entirely a non-essential element, having little or no nutritive value. The results in this study indicate, however, that small amounts of copper as well as manganese are essential to the growth of many agricultural plants. Furthermore, the amounts required may be absorbed through the leaves as well as through the roots of the plant. These results seem to be in keeping with the work of McHargue (7) and others, dealing with the analysis of plant materials. The results also indicate that the raw peat soils of the Florida Everglades are deficient in available forms of copper and manganese.

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# AVAILABLE PHOSPHORUS OF SOIL RESULTING FROM MOISTURE AND TEMPERATURE VARIATIONS, BIG HORN MOUNTAINS, WYOMING[1]

T. J. DUNNEWALD[2]

A recent paper by the author[3] called attention to an occurrence of soil bands or zones across the face of the west slope of the Big Horn Mountains in Wyoming. A close correlation between these soil zones and the soil regions of the United States was noted and similarities in chemical and organic characteristics were pointed out.

Samples of each zone of the profile of four of these soil bands were brought to the laboratory for examination. More recently, the samples were analyzed for available phosphorus by the method of Denige which has been adapted to soils work by Truog and others.[4] This method consists essentially of extracting the soil with 1/1000 N sulfuric acid and determining the phosphorus colorimetrically with ammonium molybdate and stannous chloride.

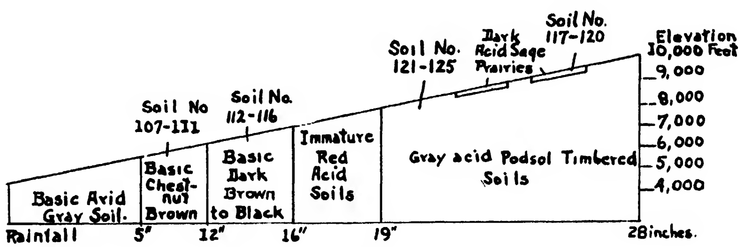


FIG. 1

Two of the soils are grayish brown in color; one, a basic arid soil; and the other an acid timber soil. (See Fig. 1.) Two are dark brown or black prairie soils, one basic, and one acid in reaction. The soil reaction, lime content, organic matter, and available phosphorus of the surface horizons of these soils are shown in Table 1.

[1]Contribution from the Department of Agronomy, University of Wyoming, Laramie, Wyo. Received for publication April 11, 1929.

[2]Assistant in Soils Investigations.

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TABLE 1.—*Characteristics of surface horizons of soils.*

| Soil type | | Rainfall, inches | Annual temperature, °F | Elevation, feet | pH | Lime content % | Organic matter % | Pounds available phosphorus per 2,000,000 pounds soil |
|---|---|---|---|---|---|---|---|---|
| Chestnut basic | (107) | 11.8 | 43 | 6,200 | 7.2 | 0.52 | 4.08 | 240 |
| Black basic | (112) | 16.19 | 38 | 6,700 | 7.4 | 0.97 | 13.4 | 115 |
| Dark brown acid | (117) | 24.8 | 33 | 8,500–9,500 | 6.0 | 0.68 | 18.7 | 94 |
| Gray acid | (121) | 27.7 | 30 | 8,500–9,500 | 5.8 | 0.56 | 7.23 | 84 |

The available phosphorus decreases with increase in rainfall. The more highly leached soils near the top of the range at 9,000 feet elevation and with 28 inches rainfall show only one-third the amount of available phosphate that is found in the arid soils at 6,000 feet elevation near the base of the mountains.

Another noticeable fact in these determinations is that the amount of available phosphorus decreases in the lower soil zones of all the profiles as compared with the surface zones where most of the organic

TABLE 2.—*Available phosphorus in pounds per acre for each soil zone.*

| Soil zone | | Description | Depth, inches | Available phosphorus, pounds |
|---|---|---|---|---|
| 107 | $A_0$ | Light grayish brown fine sandy loam | 0–1.5 | 240 |
| 108 | $A_1$ | Light reddish brown loam | 1.5–4 | 139 |
| 109 | B | Reddish brown cloddy loam | 4–14 | 216 |
| 110 | C | Pale yellowish brown loam | 14–17 | 97 |
| 111 | C | Pale gray-yellow mottled loam (lime zone) | 17–30 | 2 |
| 112 | $A_0$ | Very dark brown loam—matted roots | 0–.75 | 115 |
| 113 | $A_1$ | Dark brown loam—cloddy | 0.75–11 | 67 |
| 114 | B | Yellowish brown heavy loam | 11–15 | 47 |
| 115 | C | Yellowish brown loam—gray streaks | 15–35 | 5 |
| 116 | C | Rotten pink limestone | 35–50 | 7 |
| 117 | $A_0$ | Grayish black loam—matted roots | 0–.5 | 94 |
| 118 | $A_1$ | Very dark brown loam | 0.5–6 | 31 |
| 119 | B | Brownish yellow loam | 6–16 | 54 |
| 120 | C | Brownish yellow rotten granite | 16–24 | 57 |
| 121 | $A_0$ | Pine needles, rotten wood, decayed roots | 0–3/8 | 84 |
| 122 | $A_1$ | Dark gray brown very fine sandy loam | 3/8–1.0 | 65 |
| 123 | $A_2$ | Pale whitish gray silt loam | 1.0–6 | 34 |
| 124 | B | Brownish yellow clay loam | 6–22 | 25 |
| 125 | C | Grayish yellow and mottled rotten granite | 22–34 | — |

matter has accumulated. This is true in the basic soils as well as in those with an acid reaction. In the basic soils, the amount of lime increases in the lower zones to such an extent that the action of the 1/1000 N acid is entirely neutralized, and this results in less solution of the phosphates and a small determination of available phosphates.

The available phosphorus expressed in pounds per acre for each individual soil zone is shown in Table 2.

It is interesting to note that the weathered horizons (A and B) of soil increase in thickness from 14 inches at 12 inches rainfall, to 22 inches at 28 inches rainfall, as shown in Table 3.

TABLE 3.—*Depth of weathered zone in soils.*

| Soil | Thickness of A and B horizons | Annual rainfall |
|---|---|---|
| 107 | 14 inches | 5–12 inches |
| 112 | 15 inches | 12–16 inches |
| 117 | 16 inches | 16–19 inches |
| 121 | 22 inches | 19–28 inches |

Based on the modified Denige method for available phosphorus, the acid soils of Wisconsin are found to respond to phosphate application when reduced to 50 pounds per acre of available phosphorus in the case of sandy loams and to 75 pounds per acre for heavier soils.

The Wyoming acid soils run from 30 to 90 pounds per acre in the A horizon and the basic soils from 67 to 240 pounds of available phosphorus in the A horizon. The basic soils average 134 pounds in the A and B horizons and the acid soils average 55 pounds available phosphorus in these horizons.

Most of the Wyoming acid soils lie at such high elevations and are so rough that they are useful for summer pasture and timber growing only. The basic soils lie at lower elevations in the foothills and valleys and are capable of producing larger amounts of available plant food for the benefit of plant growth.

# NOTE

## INOCULATING WHEAT WITH LOOSE SMUT

The following simple method has been used at the Ohio Experiment Station to make inoculations in the field of loose smut, *Ustilago tritici*, (Pers.) Jens., on wheat.

Place in a distended paper bag (about 2-pound size) enough spore material so that with vigorous shaking a thick cloud of spores may be aroused. Invert the bag over a wheat head, or over several heads if they are all about the same height, using care in tipping the bag that the spore material is not lost. Hold the mouth of the bag closed about the culms with one hand, and beat the other end with the fingers of the other hand. The entire wheat spike will soon have taken on a brown coating of spores.

Wet the inside of a small glassine bag (the 2½-inch by 6-inch size used by corn breeders is satisfactory) by filling with water and emptying. Tie the glassine bag over the treated wheat head as tight as the culm will permit. The wetting may not be entirely necessary. It is provided to aid in moistening the enclosed atmosphere and plant parts.

The glassine bags need not remain on the plants until maturity. Just how soon they may be removed has not been determined. In the brief tests here, mould has not been troublesome, but should it appear, the bag would need to be removed.

Treating the heads before the opening of the earliest flowers, or after the completion of blooming, or any time between has produced infection. The opening of the first flowers near the middle of the spike provides a well marked stage in the development of the head, and has been satisfactory as a period for treatment.

Several comparisons have indicated that clipping the tips of the glume before treatment, so that spores will settle directly on the flower parts, may be expected to result in considerably more infection. A little trimming of awns on bearded varieties will facilitate application of the spores.

The accompanying tabulation represents percentages of infected spikes in a set of Fultz head-rows. The parent plants had been treated as described above in the early bloom stage and without clipping the glumes:

| Total heads per row | Smutted heads per row | Percentage smutted heads |
|---|---|---|
| 37 | 5 | 14 |
| 80 | 37 | 46 |
| 120 | 69 | 58 |
| 55 | 38 | 69 |
| 81 | 44 | 55 |
| 50 | 12 | 24 |
| 47 | 21 | 45 |
| 62 | 29 | 47 |
| 164 | 60 | 37 |
| 123 | 67 | 54 |
| 90 | 62 | 69 |
| 118 | 39 | 33 |
| 161 | 42 | 26 |
| 156 | 26 | 17 |
| 134 | 54 | 40 |
| 149 | 68 | 46 |
| 123 | 21 | 17 |
| 141 | 61 | 43 |
| 134 | 24 | 18 |
| | | Mean = 39.8 ± 2.64 |

This method was devised incidental to the wheat-breeding project at the Ohio Station. The test has not yet been thorough enough to warrant more than a notation that the method is rapid and effective. —G. H. STRINGFIELD, *Ohio Agricultural Experiment Station, Wooster, Ohio.*

# BOOK REVIEWS

## MINERALS IN PASTURES AND THEIR RELATION TO ANIMAL NUTRITION

*By J. B. Orr, Director, Rowett Institute, Aberdeen. London: H. K. Lewis & Co., Ltd., XV + 150 pages. 1929.*

This monograph reviews the whole question of the relationship between the mineral content of pastures and their nutritive value. The author has brought together in this little volume a mass of information that is of interest and value to veterinarians, agronomists, animal husbandry men, and all others who are interested in pasture problems and the value of the pasture for the grazing animal.

The book has a short preface and foreword in addition to 12 chapters. The first chapter discusses briefly the economic importance of the pastures of the British Empire and refers to the type of pasture studies that have been carried on. Chapter 2 contains some valuable data on the percentage of minerals in different kinds of pastures. The composition of the plant material grown on good pastures is compared with the composition of the crops from poor pastures. In Chapter 3 the author discusses the factors that are responsible for the wide differences in the amounts of minerals found in different types of pastures under four heads, *viz.*, (1) Species of Plants; (2) Stage of Growth of Plants; (3) Climatic Conditions; and (4) Nature of Soil.

Chapters 4 to 10, inclusive, are devoted to a consideration of the conditions under which diseases due to deficiency of minerals in pastures occur, with special reference to deficiency diseases in grazing animals in Europe, Africa, Australasia, America, and Asia. The reader will find in Chapter 11 a valuable discussion on the effect of mineral intake on the rate of production of grazing animals. This subject is taken up under the heads of (1) Direct Administration of Mineral Salts, and (2) Increasing the Mineral Content of the Pasture.

Three valuable features of the book are the summary and conclusions presented in Chapter 12, the excellent chapter bibliographies, and the index of authors. (W. H. S.)

## CORN AND CORN GROWING

*By H. A. Wallace and E. N. Bressman, New York: John Wiley and Sons, Inc. VII + 371 pages, illus. ed. 3. 1928. $2.50.*

This new edition is revised and brought up to date. It is particularly adapted for high schools and vocational agricultural teaching, with many suggestions for community projects. It covers a complete discussion of the best methods of growing corn, the botany of the plant, types and varieties, seed selection and improvement, the technic of breeding, and methods of controlling insect pests and diseases.

Corn economics is ably discussed in detail including costs of production, regional advantages, the influence of temperature and rainfall on prospective yields and prices, the corn-hog ratio, and seasonal influence on prices. The importance of the corn crop is thoroughly emphasized and many important statistics regarding corn crops are included.

It is written from the standpoint of the practical corn grower and is a good reference book in regard to best practices in corn growing and marketing. (C. B. S.)

### PLANT ECOLOGY

*By John E. Weaver and Frederic E. Clements. New York: McGraw-Hill Book Co., Inc. XX + 520 pages, illus. 1929.*

This textbook of plant ecology is particularly suited for college use and is of interest and practical value to anyone concerned with plant production. Numerous examples are given of problems in forestry, general farming, range management, and effects of overgrazing which illustrate the principles of plant ecology and their practical application. The relation of wild and cultivated plants to their natural and artificial environments is discussed in an interesting manner.

Suggestions are given for methods of studying plant communities. The influence of each factor in the plant environment is discussed in detail and the types of climax formations are explained in relation to environment. The thoroughness with which the broad subject of plant ecology has been covered is shown by the 606 selected references in the bibliography, most of which relate to problems in plant production. Although comprehensive in its scope, the book has been written in a refreshing style and is well illustrated. (C. B. S.)

## AGRONOMIC AFFAIRS

### MEETING OF SOUTHWESTERN AGRONOMISTS

The summer meeting of the Southwestern Agronomists, comprising representatives from Arkansas, Louisiana, Oklahoma, and Texas and workers in the various phases of the fertilizer industry, was held at Fayetteville, Arkansas, July 16, 17, and 18. Trips were made to Marianna, Stuttgart, and Hope to observe the experiments at the branch experiment stations at those points. The morning of July 16 was devoted largely to an inspection of the College of Agriculture, University of Arkansas, and the field experiments of the Arkansas Agricultural Experiment Station at Fayetteville. On the morning of July 17 the agronomists visited the Cotton Branch Experiment Station at Marianna, where they studied the extensive field experiments on the various phases of research work with cotton. The method of application of fertilizers to cotton is being studied here in an extensive manner. On the afternoon of July 17 the party drove to Stuttgart and examined the experimental work with rice at the Rice Branch Experiment Station. Here the results of time of application of fertilizers to rice are marked. A visit was made to the soil fertility experiments on cotton at Scotts on July 18. The afternoon of July 18 was spent in going over the interesting experiments with various fruit and truck crops on the Fruit and Truck Branch Experi-

ment Station at Hope in the southwestern part of the state. The experiments with fertilizers on the various truck crops, especially those showing the marked increases in yield of cantaloupes produced by liming the soil, were of special interest to the visiting agronomists.

## MEETING OF NORTHEASTERN STATES EXTENSION AGRONOMISTS

Representatives from Vermont, New York, Pennsylvania, Maryland, Virginia, New Jersey, Ohio, and the District of Columbia attended the conference of extension agronomists of the northeastern states held in West Virginia on August 1 and 2. The forenoon of the first day was spent inspecting the agronomic experiments under way at Morgantown and in the afternoon the party drove to Jackson's Mill, making two stops enroute to observe a corn and a potato fertilizer demonstration. At Jackson's Mill, which is the site of the State 4-H Camp, a round table discussion on the subject "Some problems retarding the development of an abundant country life in the northeastern states" was led by N. T. Frame, Director of the Extension Service in West Virginia.

## NEWS ITEMS

R. A. OAKLEY, Principal Agronomist in Charge of the Office of Forage Crops and Diseases, U. S. Bureau of Plant Industry, who, for nearly two years, has been on special detail with headquarters in California, returned to Washington on May 8 and resumed his duties as head of that office, of which Dr. A. J. Pieters had been acting in charge.

MERRITT N. POPE, Associate Agronomist in Barley Investigations, of the Office of Cereal Crops and Diseases, U. S. Dept. of Agriculture, was granted the Ph.D. degree from the University of Maryland on June 11, 1929. His graduate work was devoted primarily to plant physiology and chemistry, his thesis dealing with catalase activity and its relation to the growth curve of barley.

THE SOILS Department of the Connecticut Agricultural Experiment Station has recently installed a lysimiter equipment at the Tobacco Substation at Windsor, Conn. There are 102 20-inch cylindrical drainage tanks of three different depths, *viz.*, 10, 20, and 30 inches. The outlet tubes from these tanks lead through the walls of a well-lighted and roomy vestibule, with shelves along the sides and end for the tanks which collect the percolate. The problems associated with high applications of nitrogenous fertilizers of various types on rather sandy soils, such as prevail in the tobacco district of the Connecticut valley, are now under investigation with the facilities provided by this equipment.

WILLIAM SOUTHWORTH, who for 12 years was Agrostologist on the faculty of the University of Manitoba, resigned about a year ago and returned to his country home in England. Mr. Southworth's resignation was due to ill health. Agronomists will be glad to learn that he has recovered from a very serious operation and is now quite well again.

W. T. G. WIENER, who for 10 years was Cerealist on the faculty of the University of Manitoba, has resigned and taken the position of Secretary-Treasurer of the Canadian Seed Growers' Association with headquarters in Ottawa.

A. T. ELDERS, who was Agrostologist on the Dominion Experimental Farm, Brandon, Manitoba, has been appointed Agrostologist at the University of Manitoba, with the title of Assistant Professor.

J. W. WELSH of the Cereal Division of the Dominion Rust Research Laboratory, Manitoba Agricultural College, has secured one of the Canadian Society of Technical Agriculturalists' scholarships and will continue his studies in genetics and cytology at the University of Alberta, under Dr. Aamodt.

I. L. CONNERS, who for seven years has been in charge of the grain smut investigations at the Dominion Rust Research Laboratory, Manitoba Agricultural College, has been transferred to the Central Laboratory of the Department of Botany, Dominion Experimental Farm, Ottawa.

A. H. MEYER, Associate Agronomist of the South Carolina Experiment Station, has resigned to accept employment with the Louisiana Experiment Station. W. R. Paden, originally of Missouri and who recently was awarded the Ph. D. degree at the University of Illinois, has been appointed Associate Agronomist in his stead.

UNDER a grant of funds made by the National Fertilizer Association cooperative experiments in the proper placement of commercial fertilizer have been undertaken in South Carolina, Alabama, and Georgia. This work is under the immediate supervision of J. H. Rickborn who has headquarters at Clemson College, South Carolina.

DR. OSWALD SCHREINER, Chief of the Division of Soil Fertility of the Bureau of Chemistry and Soils, was appointed chairman of the soils section of the Fourth Pacific Science Congress held this summer in Batavia and Bandoeng, Java, where he was an official representative of the U. S. Department of Agriculture. Dr. Schreiner was also appointed chairman of a standing committee on soils, charged with the task of working out a uniform basis of classification for the soils of Pacific countries in cooperation with the International Society of Soil Science. At the meeting of International Sugarcane Technologists held at Sorabaya, Java, in June, Dr. Schreiner was chosen as chairman of the section on soils. He has made an extended trip through the tropics where he has studied agricultural conditions and fertilizing practices.

L. D. BAVER, formerly of the Agronomy Department of the Ohio Agricultural Experiment Station, was recently granted a Ph.D. degree in soils at the University of Missouri, and has accepted the position of Associate Soils Chemist at the Alabama Experiment Station.

R. E. UHLAND, Instructor in Soils, University of Missouri, has resigned to accept a position with the United States Department of Agriculture, Bureau of Plant Industry, at Stoneville, Mississippi.

JOHN B. PETERSON has been appointed instructor in soils at Iowa State College to succeed D. R. Johnson, Associate Professor of Soils, who has resigned to engage in commercial work. Mr. Peterson is a graduate of Oregon Agricultural College and during the past year has been doing graduate work at Iowa State College where he received the Master's degree in soils.

ARTHUR W. YOUNG, of Iowa State College, and Dean A. Anderson, of Brigham Young University, have been appointed to fellowships at Iowa State College where they will take up graduate work in soils for the ensuing year.

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# SYMPOSIUM ON "SOIL ORGANIC MATTER AND GREEN MANURING"

## 1. THE RELATION OF SOIL TYPE TO ORGANIC MATTER[1]

C. F. MARBUT[2]

The expression "soil type" has two entirely different meanings. As generally accepted by European pedologists the expression covers soils which have developed or are developing under the influence of a given climatic environment. The type is defined in terms of the broad, general characteristics of well-developed soils only. The character of the natural vegetation is a factor in the determination of the characteristics of the soil; but as such influence in Europe runs parallel with that of climate, the natural vegetation is not given recognition as a factor within a given climatic region capable of producing characteristics worthy of recognition as those of type value. European soil types, therefore, are usually designated as *climatic soil types*.

This basis of differentiation, first *established by Russian pedologists*,[3] is now in use by pedologists in most parts of the world. It is used in the United States for differentiating soils into broad, inclusive groups, the differentiation being based definitely on characteristics, the climate receiving recognition as the dynamic factor on the operation of which the characteristics on which the differentiation is based have been developed.

Within the United States, however, there are within one of our climatic regions, two groups of soil characteristics differing the one from the other so widely that they seem to deserve recognition as bases for type differentiation. The climatic region referred to is that covering the mid latitudes of the United States, lying south of the Great Lakes Region and approximately north of the latitude of 36 degrees, extending from the Atlantic Coast westward to the 20-inch rainfall line. The eastern part of this belt includes light-colored

[1]Paper read as part of the symposium on "Soil Organic Matter and Green Manuring" at the meeting of the Society held in Washington, D. C., November 22, 1928.

[2]Senior Soil Scientist in Charge of Soil Survey, U. S. Dept. of Agriculture, Washington, D. C.

[3]See The Great Soil Groups of the World, by K. D. Glinka. Ann Arbor. Mich.: Edwards Brothers.

podsolic soils, the western part, dark-colored non-podsolic or faintly podsolic soils, except where degraded. These soil differences correspond to differences in character of the natural vegetation under which the soil developed. We differentiate the dark-colored soils in this belt from the light colored and, tentatively at least, give them recognition as a type comparable with the other European types. This recognition is based on highly important true soil characteristics and their development under the dynamic influence of a grass vegetation.

The expression "soil type" as used in the reports of the U. S. Soil Survey, and generally in soil literature in this country, is based on soil characteristics also, but not merely those corresponding to differences in the climate or the natural vegetation of the locality in which the soil has developed, but on all the characteristics, so far as these have been determined, regardless of the factors to which they are due. These include those produced by differences of climate, natural vegetation, lithology of the parent material, relief, stage in development, and texture.

The American *soil type* is a minor unit of the European *soil type.* The boundaries of a type in the European sense constitute the boundaries of a given number of units or types in the American sense. The boundaries of one unit do not cross those of the other, but the former may include many of the latter.

The characteristics on the basis of which the soil type is defined, whether that be the type as defined by Russian pedologists or that in use by American workers, are those of the natural or virgin soil. The soil type, however it be defined, is a natural body. It is now generally agreed by pedologists that the organic matter *within* the natural or virgin soil is mainly the product of the climate and the kind of natural vegetation under the influence of which the soil was developed. It follows that the types as defined by the Russians will differ in the amount and character of the organic matter contained, while all those types as defined by American workers included within each of the European types will have about the same amount and the same character of organic matter, but the types included within different European types will differ to the same extent as the latter.

## ORGANIC MATTER AND THE EUROPEAN TYPE

The amount of organic matter can be determined by chemical analysis only. The number of analyses of virgin soils is small, not yet large enough to include all or even a large proportion of the soil types as defined by Americans. In this paper only those analyses made by uniform and well-standardized methods in the Bureau of Chemistry and Soils have been used. Samples were all taken from virgin areas and carefully collected by field men familiar with the profiles of the soils sampled. They were not collected for the purpose of organic matter determination, but the spot sampled in every case was carefully selected. These samples have been collected mainly from that part of the United States lying east of the Rocky Mountains. The map (Fig. 1) shows this distribution.

This map shows also the areas in which the climatic (European) soil types occur in the United States as accurately as that can be determined from the data available. While the number of samples from each type is not large, it is believed that in consideration of the care with which they were selected the results obtained from them are accurate within reasonable limits. The samples were collected by horizons of the soil profile and not by inches. Since horizons vary considerably in thickness, according to texture, stage of development, and probably other characteristics, it is evident that the figures obtained must represent the organic matter, or any other constituent, at different depths in different soils.

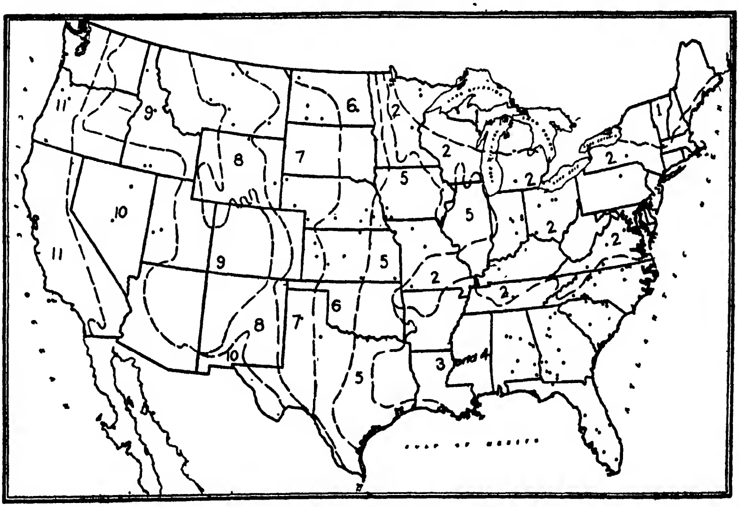

FIG. 1.—Outline map showing (a) approximate locations of spots where soil samples were collected on the results of which the curves in Fig. 2 were constructed; and (b) the approximate areas within the United States in which the soils of each of the European Types are dominant, *viz.* (1) region of Podsols (no curve in Fig. 2 for these soils), (2) region of Brown forest soils, (3 and 4) region of Red and Yellow soils, (5) region of Prairie soils, (6) region of Tschernosen and Tschernosen-like soils, (7) region of Chestnut Brown soils, and (8) region of Brown grassland soils.

In order to obtain figures showing the percentages in soils of any given type to uniform depth it would be necessary to recalculate the analyses and distribute the figures to cover uniform depth for all samples analyzed. Since this would necessarily introduce a certain amount of error, it is apparent that the true results can best be determined by plotting the actual figures for all samples analysed and for all horizons or depths, and showing the combined result as a curve. In the analyses the constituent determined was, in every case, nitrogen. The actual figures were plotted in each case so that the curves show the relation of *nitrogen content* to the *soil type*. Since the organic matter is usually obtained by multiplying the percentage of

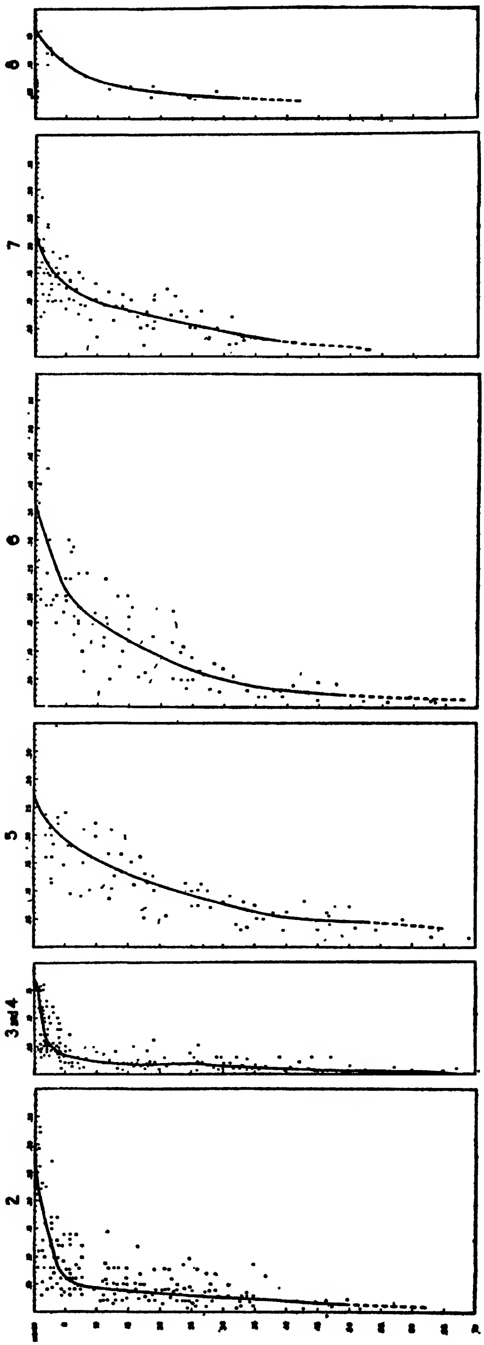


FIG. 2.—Curves showing the amount and vertical distribution of nitrogen in the soils of the Great Soil Groups or the "Climatic Soil Types" of the United States. The large figure at the top of each curve refers to the correspondingly numbered area on the map (Fig. 1) and, therefore, to the soil type for which the curve stands. The vertical column of figures shows depths from the surface. The decimal figures in the horizontal row at top of the curve shows percentages of nitrogen, expressed in hundredths.

nitrogen by some number, usually 20, the organic matter curves would duplicate the nitrogen curves. The relation of soil type to nitrogen content is the same as that of soil type to organic matter. Fig. 2 consists of a series of curves showing the percentage of nitrogen from the surface downward as well as the rate of decrease. The rate of decrease below 36 inches is obtained by projecting the curve, since only a few determinations below that depth are available.

In all cases the composition of the leaf mold or of any other kind of organic matter *overlying* the mineral soil was discarded. The figures here given are those covering the organic matter of the well drained, normally developed, mineral soil. This has been done because it is the only way by which a just comparison of the organic matter in the soils of the various types can be made. There is usually no layer of accumulated vegetable mold overlying the grass-land soils, while in some of the forest-land soils this layer may range up to nearly a foot in thickness. Since it is well known that the cultivated soils in the areas where the latter soils occur contain a very low percentage of organic matter, it is evident that an insignificant part of this organic material layer ever becomes a real incorporated part of the soil.

It will be noted that no curves are shown for the Podsols or the Gray Desert soils. A few analyses are available for both these types, but any general conclusion drawn from them would be unreliable. The type of curve in both types is known from field studies and comparisons, but the percentage of nitrogen (or organic matter) is not known.

The profiles fall into two well-defined types. First, those for the Prairie soils, the Tschernosens, the Chestnut Brown, and Brown Grass Land soils are identical in general features. The characteristic feature of the type is the relatively gradual decrease of organic matter (nitrogen) with depth. Since these are virgin soils, it is inevitable that the immediate surface will contain a high percentage of organic matter due to the fine grass roots present. The cultivated soils would not contain so high a percentage in the upper 3 inches and the rate of decrease downward would be lower.

The other type of profile is represented by those of the Brown Forest Soils and the Red and Yellow Soils. These profiles show a very rapid rate of organic matter decrease with depth in the upper 6 inches. These also being virgin soils and the organic matter present, especially in the surface soil, being derived largely from leaves and other forest debris, the percentage of organic matter in the upper 2 or 3 inches is much higher than it would be in the cultivated soil. In both cases the percentage of organic matter in the latter could probably be represented by curves similar to these below a depth of about 6 inches, while above that a projection upward of the virgin curve with a very slightly increased rate of increase to the surface would represent the curve for the cultivated soils. Whether this were true or not would depend somewhat on the treatment the soils had received, but it is apparent that the treatment received by the cultivated soils represented by the other types of curves would not affect so much the type of curve at different localities of the same soil type.

Another important difference between the two types of curves or rather between the soils represented by the two types is the depth to which any considerable amount of organic matter extends. In the Brown Forest and Red and Yellow soils, the percentage of organic matter becomes very low at shallow depth. In the others it extends to important depths. This difference is an even more striking fact in the field than in the curves. Visible organic matter coats the soil particles in the grass-land soils (the first type of profiles) in most cases to 3 feet and in many to 4 feet.

The curves show that the rate of decrease of organic matter in the soils of the Prairies is lower than in the Tschernosens and that the percentage of organic matter at any given depth below 18 to 20 inches is greater. The rapid rate of decrease in the Tschernosens is due to the fact that most of the Tschernosen samples were collected in the central and northern half of the belt, two of them in Canada where, as is well known, the surface of the virgin soil is much richer in organic matter than in the same belt further south.

The lower percentage in the deeper subsoil of these soils than in those of the Prairies, shown in the profiles, may not express the exact truth. The amount in both groups is known from field studies to be nearly the same. Since the rainfall is much lighter on the Tschernosens than on the Prairies, we should actually expect, however, on basis of this fact, just what the profiles show. The organic matter in the deep subsoil of these soils is due in part, it seems, to washing down along cracks of organic matter by downward percolation of water. The outsides of the soil structure particles are coated with dark-colored material seemingly due to this process.

No attempt has been made to compute the weight of organic matter present in these soils at various depths since this would involve a knowledge of the volume weight. This has not yet been determined for a sufficient number of soils.

## SOIL TYPE IN THE UNITED STATES

In the United States and in North America in general the soil type is defined much more narrowly than in Europe. While the definition of the type by Europeans involves only those features which are supposed to have been produced by climatic influences, other factors are taken into consideration in the American definition. In the European definition the features of the A and B horizons only are considered, and also only the features of the mature soil. In the American definition not only are features due to differences in stage of development given consideration, but each of the factors which has been involved, in any given case, in the incomplete development is given recognition. The character, especially mineralogical, of the parent material from which the soil was developed is also given recognition, since the definition involves not merely the A and B horizons but the C horizon as well. The texture of the A horizon is another factor involved in the definition.

Since the features of the A and B horizons are factors in the definition, differences in either, whether due to the influence of climatic factors or that of some of the other factors just mentioned, make it evident that within any given European type there will be more than one American type and may be many.

In general the types included within any given European type will of course differ from those in any other exactly as the respective European types differ. However, not all the American types included within any one European type will contain the same amount of organic matter as was credited to the corresponding European type. It was stated that the definition of the European type contemplated the characteristics of the mature or well developed soil only. The definition of the American type includes those of immature soils.

A soil type in the American sense involves the texture of the A horizon and also a number of other features which, grouped together, constitute what we call Series features. Type is designated by a term which connotes, not in a descriptive way however, all these latter features, followed by a term describing the texture of the surface horizon.

Some of the differences in organic matter in the various types are due to differences in texture, while others are due to some of the factors grouped as series factors. In general, a light-textured type contains a lower percentage of organic matter than a type of intermediate texture. In a group of types differing only in the texture of the surface layer the silt loam, loam, and clay loam contain a higher percentage of organic matter than sands or light sandy loams. Even in rare cases where a sandy loam may contain more organic matter than a clay loam, it is always differentiated on that basis into a different type. Some typical analyses of sandy loams and clay loams from the same region and belonging to the same series groups give a nitrogen content in the sandy loam of about 0.06% and of the clay loam of about 0.10%.

Of the other group of factors involved in the differentiation of American types not involved in that of the European type, such as characteristics of the parent rock and varying stages in development of the particular area of soil involved, the former group have relatively little influence in determining the percentage of organic matter in the soil except as these factors are involved in the second group. A fully developed soil developed from material accumulated by the disintegration in place of Granite will contain, other things being equal, the same percentage of organic matter as a soil type derived from sandstone. Two soils developed in identical climatic environment and both having attained the same stage in development, one from Granite and one from Shale, will probably contain slightly different percentages of organic matter, because the one developing from Granite will be a sandy loam, the other a silt loam or clay loam. Such soils will be differentiated into different types partly because of differences in organic matter content and partly because of differences in parent material.

The widest differences in content of organic matter in American soil types included within a given European type are due to differences in stage of development. The difference is not brought about merely because of such differences but rather because of the factors which have caused such differences in time. A soil may be undeveloped merely because it has been exposed to weathering for a short time. Alluvial deposits and recently disintegrated materials on steep slopes are examples. In such cases the undeveloped soils will differ very little in their content of organic matter from the associated mature or fully developed soils. They will be differentiated into different types, but usually not because of differences in organic matter.

## 2. ORGANIC MATTER PROBLEMS IN HUMID SOILS[1]

T. LYTTLETON LYON[2]

Among the many unexplained phenomena concerning the organic matter in soils one of those having greatest economic importance is the occasional loss of soil nitrogen not traceable to removal in crops or drainage water. That such a loss sometimes occurs is supported by experimental evidence from several sources. That it does not always occur is confirmed in the same manner.

The earlier evidence indicating the loss of nitrogen in this way was based on experiments in which soil nitrogen was determined at the beginning and end of a period of years during which crops were harvested, weighed, and analyzed. A large discrepancy between the loss of nitrogen during the period, as shown by analysis, and the loss to be accounted for by removal in crops, suggested that drainage water might not account for the difference and that it might be due in part to escape of nitrogen in a gaseous form. Numerous experiments of this nature have been reported by Lawes, Gilbert and Pugh, Snyder, Alway, Whitson, and others, but in some cases the data for nitrogen removed in crops have been only estimated.

Possibly the most striking experiment of this class was one reported by Shutt (9)[3] who found that of the loss of nitrogen after breaking and cropping a virgin prairie soil only one-third could be charged to the crops grown on it. The unaccounted loss was 75 pounds per acre annually during a period of 22 years. However, other somewhat similar experiments reported by Shutt do not imply this unaccounted loss of nitrogen. Lipman and Blair (1) also found an average annual unaccounted loss of 70 to 100 pounds in soil cropped without legumes but heavily manured. The experiment covered a period of 20 years.

Wright (10) conducted experiments with soil in large buckets for one season. There was no drainage from the buckets. A number of different plants were grown. The soil of each bucket was analyzed at the beginning and at the end of the experiment. In the case of every crop except one the nitrogen lost from the soil, as shown by analysis, was greater than the quantity contained in the crop.

There have been large losses of nitrogen reported by other investigators who kept no record of the nitrogen in the crops grown. These losses could probably not be accounted for by removal in crops. In recent years some experiments have been conducted in which the entire income and outgo of nitrogen have been measured. In experiments of this kind the soil at the beginning and end of the experiment period was analyzed, as were also the crops removed, the manure or fertilizer applied, the water added or received as rain and snow, and the drainage water from the soil.

[1]Paper read as part of the symposium on "Soil Organic Matter and Green Manuring" at the meeting of the Society held in Washington, D. C., November 22, 1928.

[2]Professor of Soil Technology and Head of Department of Agronomy, Cornell University, Ithaca, N. Y.

[3]Reference by number is to "Literature Cited," p. 957.

On the other hand, Russell and Richards (8) found that the nitrogen contained in the drainage water of one of the Rothamsted drain gauges through a period of 35 years, less the nitrogen contained in the rain water for the same period, was just about equal to the quantity of nitrogen lost from a contiguous piece of land during the same period as deduced from chemical analyses. The soil in both cases having been kept free of vegetation, the nitrogen removal in crops was not a factor.

Mooers, MacIntire, and Young (6) kept a record of the nitrogen removed in crops and drainage water from soil contained in lysimeters for a period of five years. Determinations of nitrogen in the surface 6 inches of soil were made at the beginning and end of the experiment. Alfalfa was grown on some tanks and tall oat grass on others. There was no indication of loss of nitrogen in gaseous form from the soil planted to alfalfa, but in two out of seven tanks planted to grass there was indication of such a loss. In these two tanks there was only 6 inches of soil in one case and 18 inches in the other.

At the Cornell University Experiment Station the soil has recently been removed from lysimeter tanks for which the history of accretions and losses of nitrogen is available for 15 and 17 years. Determinations of nitrogen in the surface 12 inches of soil were made at the beginning and end of the experiment. A record was kept of the nitrogen applied in manure and seed and that received by the soil in rain and snow, also that removed in crops and drainage water. Three cropping systems were practiced as follows:

1. A five-year rotation of corn, oats, wheat, and timothy (two years).
2. A five-year rotation of corn and soybeans, oats and peas, wheat, timothy and clover (two years).
3. Soil kept bare of vegetation for 10 years, then cropped to corn, oats, timothy (three years).

In each cropping system one tank was limed and one was not. The soil was not greatly in need of lime but enough so to produce larger legume crops when limed, but not larger crops of cereals. The results are shown in Table 1.

TABLE 1.—*Nitrogen balance in lysimeter soil in pounds per acre.*

| Explanation of steps in calculation of amount of nitrogen lost in gaseous form | Cropping systems: No legumes 17 years, Not limed | No legumes 17 years, Limed | Legumes and non-legumes 15 years, Not limed | Legumes and non-legumes 15 years, Limed | No crops 10 years, cropped 5 years, Not limed | No crops 10 years, cropped 5 years, Limed |
|---|---|---|---|---|---|---|
| Removed in crops and drainage.... | 1,129 | 1,075 | 1,462 | 1,679 | 1,001 | 734 |
| Added in manure, seed, and rainfall | *950* | *950* | *694* | *694* | *694* | *694* |
| Difference, or expected removal.... | 179 | 125 | 768 | 985 | 307 | 40 |
| Loss or gain as shown by analyses at beginning and end of experiment | *—182* | *—75* | *+37* | *+73* | *—689* | *—442* |
| Discrepancy between expected removal and loss or gain shown by analyses.................... | —3 | +50 | +805 | +1,058 | —382 | —402 |
| Average annual discrepancy...... | —1/6 | +3 | +54 | +71 | —26 | —27 |

With reference to the unexpected gain or loss of nitrogen a few things may be noted as follows:

1. With a crop rotation containing no legumes there was no loss of nitrogen that could not be accounted for by removal in crops and drainage water.

2. In the soil on which legumes were grown with non-legumes there was a gain in nitrogen.

3. In the soil kept bare for 10 years and then cropped for 5 years there was an average annual loss per acre of about 25 pounds of nitrogen that could not be accounted for by removal in crops and drainage water. Presumably this has escaped in a gaseous form.

4. Liming this particular soil did not appear to affect the loss, but as previously remarked the soil was not greatly in need of lime, except for the more sensitive legumes.

Reviewing the various experiments noted above and possibly a few others, there seems to be some reason to believe that there may be, under certain conditions, an unexplained loss of nitrogen from soil. Unfortunately, the strongest evidence comes from experiments in which there was no record of loss of nitrogen in drainage water. However, when the loss amounts to 70 to 100 pounds to the acre yearly above the nitrogen removed in crops it is difficult to believe that the drainage water will account for this entire amount. Especially is this the case with the experiments reported by Shutt, which were conducted in regions of rather low rainfall.

It is worth while to examine the experiments further in order to see whether it is possible to discover what conditions favor this unexplained loss of nitrogen.

Russell (7) has discussed the subject of the possible loss of gaseous nitrogen. He concludes that soils of high nitrogen content or soils heavily manured lose nitrogen in this way when placed under cultivation. Also, that land allowed to lie in grass or weeds without stirring loses little or no nitrogen in this way. Without going further into an analysis of the various investigations that cover this phase of the subject it may be said that they all appear to support these conclusions.

The Cornell experiment seems to point to a lack of vegetation as another factor in increasing loss of nitrogen in a gaseous condition. It will be noticed that the only loss of this kind occurred in soil kept free of vegetation for 10 years. The unplanted soil did not receive more stirring than that subjected to a crop rotation. The greater loss could not, therefore, be occasioned by more aeration. It seems probable that the absence of plants on the soil for a period of 10 years is responsible for the apparent loss of nitrogen.

The figures given in Table 1 show only the evident losses or gains of nitrogen from the soil. If fixation of nitrogen took place through the activities of either symbiotic or non-symbiotic organisms, the nitrogen so fixed must have been lost in addition to that computed in Table 1. For instance, any quantity of nitrogen that was fixed in the soil growing a rotation of non-legumes must have been lost in gaseous form. Otherwise, the soil would have shown a gain of this much nitrogen instead of showing no gain or loss. If the uncropped soil had fixed nitrogen and if it had not escaped in gaseous form, the

loss of nitrogen would have been less than is shown in Table 1. If any fixation took place the losses of gaseous nitrogen were greater than the figures obtained by these calculations.

It is also probable that the fixation of nitrogen in the soil planted to legumes was greater than the calculated gains. Fixation to the extent of 54 and 71 pounds to the acre annually is evident from the calculations, but if loss of gaseous nitrogen occurred fixation must have been greater than is indicated by these figures.

The losses of nitrogen arrived at by the calculations contained in Table 1, therefore, do not represent the maximum losses of nitrogen if fixation occurred. However, since the soil with non-legumes did not show any loss of nitrogen while the bare soil lost a considerable quantity, this difference may have been due to a greater fixation in the cropped soil.

The loss of total nitrogen in fallow soil has been brought out by another experiment at the Cornell Station (4) in which a number of cover crops were raised annually on the same plats for a period of 10 years. Four contiguous plats were kept continually in grass throughout this entire time. The soil covered with grass gained 415 pounds to the acre during the 10 years, the cover crop plats, which were kept free of vegetation each year from early spring until the middle of July, lost from 217 to 412 pounds of nitrogen to the acre when only non-legume cover crops were grown throughout the duration of the experiment.

Whether liming soil causes an increase in the loss of gaseous nitrogen is not so clearly indicated by the published experiments. To supply information on this subject an experiment should furnish a record of the removal of nitrogen in drainage water. It is quite well established that liming increases the quantity of nitrogen in the drainage water of some soils and also induces a larger removal of nitrogen in the crops grown on some soils. Lower nitrogen content of limed soils may then be due to removal in drainage water or crops and not to escape of gaseous nitrogen, unless the experiments are designed to measure removal in these forms. While there is plenty of experimental evidence that liming causes a decrease of nitrogen in some soils, especially when no legumes are grown, there does not appear to be sufficient data to warrant a statement as to its effect on loss of nitrogen in gaseous form.

In the Cornell lysimeter experiments there was no greater loss of gaseous nitrogen in limed than in unlimed soil. However, this soil did not respond to lime either in formation of nitrates or in growth of non-legumes.

Whether the soil gains or loses in nitrogen content when planted to legumes depends on the balance between the factors that add nitrogen and those that remove it. The former include manures, seeds, rainfall, and fixation by both symbiotic and non-symbiotic organisms. The removals may be due to absorption by plants, solution in drainage water, and conversion into a gas which escapes.

The soil of both tanks planted to legumes gained nitrogen, but the limed soil made a greater gain than did the unlimed soil. Liming caused increased fixation and this obscured the extent of the loss in gaseous form. Fixation by non-symbiotic organisms may also mask this loss of nitrogen when only non-legumes are grown.

If soils of high nitrogen content lose rather large quantities of nitrogen in gaseous form even when they are cropped in a suitable rotation, it becomes a question whether we should try to maintain a high content of nitrogen in arable soils. Although it is possible to build up the nitrogen content by leaving the land in some perennial crop like timothy or alfalfa for some years, yet when placed under cultivation this soil loses nitrogen very rapidly. Likewise, when highly manured, a tilled soil loses much nitrogen.

The loss of gaseous nitrogen is a wasteful one because it is possible to recover it only slowly. In the experiments by Lipman and Blair already referred to, where there was heavy manuring, the losses of nitrogen amounted in some cases to more than the quantities removed by the crops. Evidently, such heavy manuring is an uneconomical practice. By the rather frequent growth of legumes or use of inorganic nitrogen, it is possible to keep the nitrogen of the soil in an active form even when only the legume crop residues are plowed under. It may be more economical to maintain a rather low nitrogen level in the soil and to keep the nitrogen active by maintaining a narrow N-C ratio rather than to try to build up a high nitrogen content.

This loss of total nitrogen from soils is quite distinct from the disappearance of nitrate nitrogen which occurs when conditions are favorable for the growth of nitrate nitrogen assimilating organisms.

It has been found that the nitrate nitrogen in soil may disappear by being converted into organic form, and that when conditions are again favorable for nitrate formation, a part of the nitrogen at least will reappear as nitrate. The disappearance and reappearance of nitrate nitrogen has been demonstrated experimentally. Meggitt (5) found that nitrate nitrogen disappeared from soil under normal conditions and was completely converted into organic form. This he did by adding potassium nitrate and sugar to a soil of known nitrate content, allowing them to stand for several days at optimum moisture content. A similar culture was prepared without potassium nitrate. Any fixation of nitrogen might be presumed to go on equally in both cultures. He reports that determinations of total nitrogen at the beginning and end of the incubation showed all the nitrate nitrogen to have been converted into organic nitrogen. None was present as ammonia.

That this organic matter may be reconverted into an available form has been shown by an experiment at Cornell (2) in which plats of land treated with several graduated quantities of nitrate of soda for a few years was planted to rye for a year after the applications ceased. Although all the nitrates had practically disappeared in the autumn and the applications had been discontinued, the yields of rye the following year were in the order of the extent of the previous application of nitrate of soda to the respective plats.

TABLE 2.—*Reappearance of nitrate nitrogen.*

| Nitrate of soda applied annually, pounds per acre | Nitrates in soil Oct. 28, 1920, pounds per acre | Yields of rye in 1921, pounds per acre |
|---|---|---|
| 0 | 0 | 900 |
| 100 | 0 | 1,250 |
| 300 | trace | 1,800 |
| 900 | 10.2 | 3,787 |

Meggitt's experiment shows that nitrate nitrogen may disappear without loss of total nitrogen from the soil. The Cornell experiment shows that the nitrate nitrogen that disappears may be, in part at least, reconverted into an available form. The disappearance of nitrate nitrogen does not necessarily mean a loss of total nitrogen from soil.

The loss of total nitrogen from soil may have an important bearing on the practice of using cover crops in orchards. A common method is to plow under a cover crop in the early spring and to keep the land cultivated until midsummer, then to replant the cover crop and keep the soil covered until the following spring.

In the experiment with cover crops at Cornell which was previously alluded to a practice such as that described was continued for 10 years. In addition, certain plats were kept continually in grass for the 10-year period. Analyses of the soil for total nitrogen were made at the beginning and end of the experiment, and each year determinations of nitrates were made at intervals throughout the spring and that part of the summer during which the soil was bare. After 10 years the grass was plowed up and all the plats were planted to corn one year and to oats the next year. Table 3 states the results of the analyses and the combined yields of corn and oats.

TABLE 3.—*Experiment with cover crops.*

| | Total N in soil | Pounds to the acre Average nitrate N for May, June, and July | Total yield of corn and oats |
|---|---|---|---|
| Grass | +415 | —— | 28,900 |
| Vetch | — 42 | 50.3 | 26,800 |
| Rye | —217 | 31.7 | 22,100 |
| Peas | —380 | 30.8 | 18,100 |
| Oats | —382 | 26.2 | 19,500 |
| Buckwheat | —412 | 19.4 | 15,000 |

A rather striking feature of this table is that it shows a loss of total nitrogen in the soil of all the plats on which cover crops were grown. It will be remembered that no crops were removed from the soil. On the other hand, under grass there was a very decided gain in nitrogen. There would appear to be a similarity between the effect of keeping the soil free of vegetation in the lysimeter experiments and keeping it fallow on the cover crop plats. It suggests strongly that a bare soil, especially when stirred, loses nitrogen in gaseous form.

Under grass the conditions were quite different, for the soil was not stirred from the beginning to the end of the experiment. An untilled soil planted to a perennial crop appears to conserve nitrogen whether it be planted to a legume or a non-legume.

There was a definite relation between the loss of total nitrogen and the accumulation of nitrates. High nitrate content was associated with a small loss of nitrogen. The nitrogen lost appears to have been that which was in a readily nitrifiable form. A similar relation obtains between the loss of nitrogen and the yield of corn and oats. This loss of nitrogen has affected the productivity of the soil.

Taking into consideration the various investigations bearing on this subject and attempting to reconcile and evaluate the results it would appear that while much uncertainty attends the whole subject, a few tentative conclusions may be offered at this time.

1. The loss of gaseous nitrogen may, under some conditions, cause a greater removal of nitrogen from a soil than occurs through absorption by crop plants.

2. The conditions that favor a large loss of this kind are (a) tillage or stirring the soil in any way, (b) absence of plant growth, (c) high nitrogen content of a soil, (d) application of large quantities of nitrogenous manures, and (e) possibly the application of lime to some soils.

3. The loss of gaseous nitrogen, as calculated by the method used in this review of investigations, is subject to error which arises from failure of the method to detect the amount of nitrogen which may be fixed by soil organisms. Consequently the losses here calculated are probably less than actually occurred.

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## DISCUSSION

The problem of the economy of nitrogen in cropped soils is one, the various aspects of which have received consideration by many investigators, beginning with Boussingault, designated by E. J. Russell as the "Father of Agricultural

Chemistry," and including such famous workers as Liebig, Berthelot, Schloesing, Muntz, Hellriegel, Warington, Lawes, Gilbert, Wagner, Atwater, and many others.

A notable contribution to this subject has also been made by Lyon and his associates of which the paper just presented is only a small part. In this paper certain conclusions are drawn and certain suggestions as to practice are made which are of considerable interest and significance.

Considering first the conclusions we find the following:

1. That the loss of gaseous nitrogen may, under some conditions, be greater than the loss through crop removal.
2. That tillage; the absence of plants; a high nitrogen content; the use of large amounts of nitrogenous manures; and, possibly, the use of lime favor such losses.

It is conceivable that nitrogen may be lost from the soil in gaseous form as a result of five possible processes:

1. There may be an escape of part of the ammonia arising in the process of ammonification.
2. There may be a reduction of nitrates to free nitrogen as a result of an alternation in the processes of oxidation and reducti on.
3. There may be a loss of elemental nitrogen in the process of the oxidation of ammonia to nitrous acid since nitrogen is possibly an intermediate product in this process.
4. There may be a loss of nitrogen, as the element, resulting from the interaction of nitrous acid with the $NH_2$ group of the amino acids.
5. There may be a loss of nitrogen, as such, as a result of the decomposition of ammonium nitrite that may be formed in the process of nitrification.

These various processes have all been given more or less consideration by the several investigators of this problem.

There are two very important facts to consider in this connection. One of them is that the C-N ratio in soils of humid regions tends to maintain itself at about 10 to 1. The other is that the nitrogen content of any given soil tends to come to equilibrium at a point that depends upon the nature of the soil, the effective climate, and the cropping system. Doryland and Waksman have made important contributions to our knowledge concerning the first of these facts. A highly significant contribution as to the second of these facts has recently been made by Jenny.

If the organic residues that are left in the soil by a crop or that are applied to the soil by the farmer have a wider C-N ratio than 10 to 1, an adjustment is relatively soon effected, the extra carbon disappearing into the atmosphere. If the C-N ratio is less than 10 to 1, there is quite likely to be a loss of nitrogen before the adjustment of the ratio is effected.

When we consider the second fact, *viz.*, that the soil tends toward an equilibrium as to its nitrogen content, it is apparent that, as Dr. Lyon points out, any piling up of nitrogen in the soil as a result of some especially large application of organic nitrogenous manures, the excessive growth of legumes for soil improving purposes, or the accumulation of nitrogen resulting from keeping the soil in timothy or bluegrass, must be soon dissipated when the soil is again brought back to its normal condition by cultivation. This nitrogen might, of course, be lost in the drainage or be removed in excess quantities by a crop. Normally, a considerable portion of it is quite likely to be unaccounted for in either of these and must be sought in the atmosphere.

It would appear desirable that we have a continuous record of the nitrogen content of the soil, that is, a week by week, or perhaps month by month, record of its nitrogen in order to see the curve that must certainly obtain. There may be times when quite rapid fixation takes place and other times when equally rapid losses occur.

Bonazzi has nicely brought out the point that nitrogen-fixing bacteria choose the line of least resistance. If nitrates are available, these are used. If not, and the conditions for fixation are otherwise favorable, it takes place.

How else can we account for the fact that soils planted to timothy and bluegrass, notwithstanding the removal of nitrogen in the crop, tend to become richer in nitrogen? The conditions are favorable for the process. There is no nitrate nitrogen under a timothy sod. Except as we accept the point of view of the Italian

workers, recently emphasized by C. B. Lipman, that non-legume plants are capable of collecting atmospheric nitrogen, there is difficulty in finding any other explanation.

Dr. Lyon presents a point of view concerning the waste of nitrogen that may occur as a result of the plowing under of large amounts of organic manures, high in nitrogen, that is of considerable interest in several ways. It argues for the substitution of mineral fertilizers for part of the animal manure used, when available, in such liberal amounts by market gardeners. It also raises the question as to whether, if one has any other important use for it, large quantities of green-manure legume crops should be plowed into the soil. The question is not, does it pay, but does it pay best to plow under protein material that has a high value for feeding purposes.

It seems quite logical, as Dr. Lyon points out, to maintain the soil at a relatively low but active point as to its nitrogen content rather than to attempt to raise it high above its natural point of equilibrium by the use of organic manures and suffer the losses that are very likely to occur.—F. E. Bear.

## 3. ORGANIC MATTER PROBLEMS UNDER DRY-FARMING CONDITIONS[1]

J. C. RUSSEL[2]

Agronomists representative of every dry-land section of the United States and Canada have stated at one time or another, that aside from water, organic matter is the most important soil problem of their section. In many cases this statement has been based on first-hand experience, the counterpart of which is rare in humid sections in this generation. Virgin land has been seen brought under the plow. The gradual disappearance of fibre and degranulation of structure have been observed. An increasing tendency toward erosion by wind and water has become apparent. The ease and satisfaction of implement performance in many cases has been seen impaired and the labor requirement in tillage increased. And, in spite of remarkable strides in agricultural efficiency since the virgin sod was turned, there are scores of cases with which dry-land agronomists are personally familiar, where the yielding capacity of the soil has been considerably reduced.

Analysis of soils from fields that have been cropped for extended periods has shown extensive losses in the organic matter portion. Considering the theoretical functions of organic matter, coupled with such first-hand observations as those just mentioned, what is more logical than the conclusion that the depletion of organic matter is serious?

There is no question but what organic matter has been depleted in dry-land sections under some cropping systems. State-wide studies of organic matter depletion have been under way in Nebraska for several years. The following is a digest of the data obtained to date on 67 fields from all sections of the state. These are fields which have been cropped mainly to grain without addition of manure or growth of legumes or without obvious water or wind erosion.

Nine fields under cultivation for three to seven years have lost 6.5% of their original organic matter content. Nine fields under cultivation for 8 to 15 years have lost 12.4%. Twelve fields under cultivation 17 to 30 years have lost 26.8%. Twenty-five fields under cultivation 32 to 44 years have lost 26.2%. Twelve fields under cultivation 45 to 60 years have lost 28.0%. Loss of organic matter in all these cases is based on a comparison of the analysis of the top foot of the cultivated soil with adjacent and comparable virgin land. Fifteen of these fields that have been under cultivation from 30 to 60 years show in portions which have been subjected to water erosion an average loss of 56.0% of organic matter as compared with 27.1% loss on leval uneroded portions of the same fields.

[1]Paper read as a part of a symposium on "Soil Organic Matter and Green Manuring" at the meeting of the Society held in Washington, D. C., November 22, 1928. Contribution from the Department of Agronomy, Nebraska Agricultural Experiment Station, Lincoln, Nebr. Published with the approval of the Director, as Paper No. 81 Journal Series.

[2]Agronomist.

The data above seem to indicate that depletion of organic matter is most rapid during the early years of cropping and becomes less as time progresses. After about 30 years the soil seems to attain a base level of organic content 25 to 30% lower than the original. One may conclude from this that the greater part of organic depletion has already occurred, and that the future of our soil with respect to organic content will not be much worse than the present.

The agronomists at the Nebraska Station, like most others elsewhere, have in the past taken the depletion of organic matter seriously for three reasons. The first is concerned with nutrient nitrogen, the second with moisture, and the third with structure and tilth.

The loss of organic matter means of course the loss of nitrogen. The better virgin soils of dry-land Nebraska contain from 4,000 to 6,000 pounds of nitrogen per acre in the upper 12 inches and the loss of a fourth to a third of this supply is in itself no inconsiderable item. Most serious, however, is the fact that the availability of the nitrogen remaining in the soil does not appear to be as high as it was originally. It has been quite definitely established that those Nebraska fields which have suffered the greatest depletion of organic matter, other things being equal, have the lowest capacity to produce nitrates. As an example of the more extreme conditions may be cited the case of two fields near Lincoln, both under cultivation about 40 years, one mismanaged and carrying only 1.60% of organic matter in the top foot, the other well maintained and carrying 3.66% of organic matter. The first field has suffered a loss of 69% of its original organic content; the second 29.1%. In the fall of 1927 these two fields were prepared for wheat in a fairly comparable and thorough fashion. In April, 1928, the nitrate-nitrogen content of the poor soil to a depth of 3 feet was 10.6 pounds per acre; of the good soil, 64.5 pounds per acre. The yield of wheat on the poor soil was 7.46 bushels per acre, and on the good 26.62 bushels per acre. Moisture conditions in April and continually thereafter were in favor of the poorer soil.

Organic matter is presumed to be of value in the water relations of soil. Nowhere in the country would its value in this respect be more important than in dry-land sections. Under dry-land conditions three questions must be asked. First, Does organic matter contribute to water intake? Second, Does it contribute to the capacity of soil to retain water against loss by evaporation? Third, Does it contribute to the water-retaining capacity of the subsoil?

At Lincoln an experiment was conducted in which 40 tons per acre of well-rotted manure were incorporated in the surface few inches of a plat laid out on a hillside of uniform 2% slope, this plat being thoroughly sampled at frequent intervals throughout the season extending from May 12 to October 14, 1924. An adjacent comparable check plat of average condition of organic matter content was sampled in a corresponding manner. Both plats were kept bare of vegetation throughout the period but were not cultivated, nor was the surface disturbed more than the barest minimum in removal of vegetation. The purpose of the experiment was to determine the

effect of increased organic content in intake and conservation of rainfall under conditions where surface structure was a possible factor in loss by run-off in wet weather, and loss by evaporation in periods of dryness.

During the 144-day period of the experiment a total of 14.98 inches of rain fell. In the check plat, 0.94 inch, or 6.3%, of this water was found at the end of the season. In the treated plat 2.93 inches, or 19.6%, was found. The addition to the organic content of the soil had trebled the total conservation of water.

The frequencies of sampling permitted an analysis of the data from the standpoint of the effects of the treatment during wet and dry periods. As a total for all wet periods, that is periods during which heavy rains fell, 2.09 out of 9.04 inches of rainfall were accounted for in the soil in the treated plat and 2.63 inches in the untreated plat. Where the manure had been added, 7.2% more of the rainfall was lost. As a total for the dry periods, that is periods during which no rains fell in sufficient quantity more than to wet the ground, 0.10 inch of water was gained by the manured plat and 1.40 inches was lost by the check plat.

It seems safe to conclude that under the conditions of this experiment a high organic content was advantageous in dry weather and a detriment in wet, but on the whole of considerable value. The reasons for these particular conclusions appear to lie in the character of the soil. The soil is a clay loam that shrinks and cracks considerably on drying. The presence of these cracks was an advantage when rains came, for they permitted ready penetration of water to considerable depth. They were a disadvantage during dry weather for they permitted excessive loss by vaporization. It was obvious that the organic addition reduced the tendency of the soil to crack.

The conditions under which such experiments are conducted are highly important and if the value of organic matter in water relations is to be soundly established, numerous experiments of this and other types must be conducted out of doors under a wide variety of conditions of soil, slope, weather, organic content, and cultivation.

Under typical dry-land conditions in western Nebraska, the soil is rarely a clay loam. It is mainly a very fine sandy loam in the surface, or coarser, and readily forms a natural mulch. It is entirely possible that practical additions to the organic content on such soils in that section would be entirely uneffective in water relations.

But, some one will say, organic matter certainly will increase the water-holding capacity of the soil. There is no question as to the validity of that statement. In sandy soils under humid conditions where loss of water and nutrients by percolation is of concern, incorporation of organic matter with the surface soil is undoubtedly of importance in reducing percolation losses.

Under dry-land conditions it is important that rains penetrate quickly and deeply below the surface, otherwise they are subject to loss by evaporation. It may be entirely possible that a high organic content in the surface soil is precisely what is not wanted in sandy soils when the subsoil has fair water-holding capacity. Could organic

matter be added in quantity to the subsoil, it would seem logical to advocate this practice. The small changes in organic content in the subsoil that accompany either depletion or addition in the surface are probably inconsequential, as far as effects on water storage are concerned.

Referring again to the moisture experiment conducted at Lincoln, it might be noted that out of 14.99 inches of rain that fell on a 2% uncultivated and bare slope, 12.05 and 14.04 inches were lost on the manured and unmanured plats, respectively. In our interest in the 1.99 inches saved by the organic addition, we should not lose sight of the 12 or 14 inches lost for other reasons. It is entirely possible that efforts directed toward restoration of organic matter might, as far as water relations are concerned, be several times better directed toward other methods of conservation.

It is strikingly obvious that profound detrimental changes in structure and tilth have accompanied organic matter depletion. In dry-land sections soil drifting is a serious problem and fibre and coarse granules, as in new soil, are a great advantage. The porosity and sponginess that accompany such new soil conditions are important also in intake of water on both level and rolling land. Viewing it solely from the quantitative standpoint, Will restoration of organic matter bring back the mechanical condition that obtained when land was new? We are afraid it will not. Abundant evidence is to be found scattered over the dry-land region of straw stacks that have decayed and have given to the soil an organic content equal to or higher by considerable than that in virgin sod. Never does such soil have the unique fibrousness and granulation that obtains a few years after sod is broken.

The impairment and improvement of structure should be looked upon as more than a problem of loss or gain in organic content. The rôle of organic matter in imparting stability to the soil granules must be better understood. It is highly possible that granulation apart from fibrousness can be restored advantageously by processes in which any large increase in organic content is of minor concern. Putting land into grass is an illustration of a practice by which both granulation and fibrousness are increased far out of proportion to the organic matter added.

Another physical problem is the determination of the effect of organic matter on tilth. In dry-land regions, tillage is the farmer's main method of attaining high yields. He tills to conserve moisture, eradicate weeds, and to prepare the seedbed. Any action of organic matter which would lighten draft, or make one disking or harrowing do where two might be required, or make possible early entry onto fields where otherwise there would be delay would seem to be important. The one item of being able to get into a field a half day earlier after each good rain might mean more to a farmer than all the other values of organic matter that have been discussed. Such problems await solution as far as dry-land regions are concerned.

Turning now from problems which have to do with the function and importance of organic matter, let us discuss next some of the

problems of its restoration. Assuming that it is required and must be maintained, What practices shall the dry farmers be advised to follow? First, What shall they be advised about legumes?

On typical southwestern Nebraska dry land, less than 1 acre in every 30 under cultivation is in legumes and the acreage is not increasing. There are several reasons for this, such as difficulties in getting a stand and shortage of moisture, however, one of the most important is the detrimental effect that legumes are known to have on the succeeding grain crops. One of the important organic matter problems in dry-land Nebraska is how to overcome the tendency of crops to "fire" for several years after alfalfa is broken up.

The "firing" of crops following legumes is probably due largely to excessive nitrate production which leads to rapid growth and premature exhaustion of the limited soil moisture. Theoretically, any practice of culture or amendment which would repress nitrate production would seem effective. The addition of straw has been advocated by Sievers and Holtz and is practiced in dry-land Washington.

The injurious after effects of growing sorghum due, according to Conrad, to repression of nitrification by sugar in stubble and roots, may be a blessing in dry-land regions. Instead of following sorghum by legumes, as Conrad suggests, as a means of overcoming the detrimental effects of the former, why not follow legumes by sorghum to overcome the detrimental effects of the legume? As a matter of fact, the practice of following alfalfa by sorghum was well established in the writer's neighborhood in central Kansas 25 years ago.

Another practice followed in the less arid portions of dry-land Nebraska is to pasture alfalfa heavily for several years until it has run to grass, and then plow up the grass. In the light of the repressive effects of grass roots so well established by Lyon and others at Cornell, the practice seems to have elements of scientific soundness.

Sweet clover does not seem to induce as serious, lasting, and widespread detrimental effects on subsequent crops as alfalfa and on that score has much more reason for inclusion in an organic matter program in a dry-land section.

Curiously, northwestern Nebraska, which has the same rainfall as the southwestern section, has a higher percentage of dry-farming land in legumes than any other section of the state. One acre in every seven or eight is in legumes, and one sixth of the legume acreage is sweet clover. This is probably an unusual dry-farming situation. Several features of the agriculture in that section contribute to it. There is considerable livestock and the forage is in demand. Furthermore, it is a good alfalfa seed producing region, hence the crop is profitable even though the forage yield is low. Most important, from the soils standpoint, however, is the fact that alfalfa soon thins out and grows up with grass, and when it is plowed up the ground goes into potatoes which are not damaged by firing as seriously as grain crops.

Farm manure has the same reputation among dry-land farmers in Nebraska as has alfalfa. It is said to fire the crops. In many cases

this effect is traceable to application at excessive rates. When used sparingly, at rates not to exceed 5 tons per acre every few years, manure has not been detrimental but rather somewhat profitable. However, the supply of manure in dry-land sections is a problem. Livestock are conspicuously scarce in dry-land regions, and the rapidity with which numbers are increasing gives no assurance that the manure supply will ever cut much of a figure in organic matter maintenance.

What shall the dry land farmer be advised to do about crop residues? This is one of our most important organic matter problems for the reason that these residues contain on the average more carbon than the soil is losing and a third or more of the nitrogen used by the crops, and in them the farmer has a material which if usable should go a long way toward keeping up organic content.

In dry-land Nebraska the main crop residues are wheat straw and corn stalks. Up to recently very little of the harvested straw has been returned, and that usually after it has become well rotted. The advent of the combine means of course that from now on a large portion of it will go back on the land. The advent also of the one way disk plow means that the straw if not burned is going to be worked intimately throughout the surface layer. In light of the well-established repression of nitrification by fresh straw one wonders what the outcome will be. In western Nebraska many farmers, probably half, already have adopted the practice of burning the stubble fields, and insist that immediate yields thereafter are enhanced.

In the irrigation rotations at the Scottsbluff Experimental Substation in western Nebraska there are two plats that have been growing spring wheat continuously since 1912. From one of these plats all straw has been removed. On the other, all straw has been returned. The mean yield for 14 years of the first is 17.2 bushels per acre and of the second, 16.8 bushels. The mean yields of the last 5 of the 14 years are 11.4 and 10.3 bushels, respectively. These two plats were carefully sampled at the end of the 14-year period. The nitrogen content of the top foot of soil of the plat to which 13 crops of straw had been returned was 0.071%. The nitrogen content of the plat where all straw was removed was 0.067%. The difference is negligible. In adjacent tests manure and legumes have significantly increased nitrogen content. The above performance of straw was under irrigation. What the results of a similar experiment would be under dry-land conditions is conjectural.

How can the value of straw be enhanced? It is no longer a problem of making artificial manure out of straw in the stack. It is a problem of treating the straw in the field; of getting it to decay rapidly without repression of nitrification and, if possible, without undue loss of carbon.

The return of corn stalks fits well into dry-land practice. Repressive effects therefrom have not been noted, or if observed, have been charged to mechanical conditions and tests. The corn stalk problem in organic matter maintenance awaits investigation.

Growing of green manure crops for purposes of organic matter improvement is a practice that has been quite completely studied at several dry-land experiment stations and quite definitely condemned.

The possibilities of organic matter restoration through putting semi-arid lands back into grass await investigation. The available information concerning increases in nitrogen and carbon that result thereby and the numerous observations of the beneficial effects of grass roots on structure give hopes for the practice. Dry lands have been abandoned to grass in early years of colonization due to hard times, and it is conceivable that large acreages will be abandoned again due to soil conditions, however, it is extremely unlikely. Any advantages that accrue from grass will more likely come through deliberate practice of diversified farming that includes that crop in the rotation. The development of adaptable dry-land hay grasses would give point to investigations of the effect of regrassing on organic content.

The increase in the nitrogen content which accompanies regrassing has been explained as being due to free nitrogen fixation. It is well known that fixation of nitrogen may also occur in the absence of grass. Under irrigated conditions in some semi-arid sections free fixation is often enormous. Apparently not enough is yet known about all the factors involved in azofication to justify hopes that organic matter can be maintained in dry-land regions. Certainly, the problem of azofication is one that requires consideration in relation to organic matter maintenance.

From the foregoing discussion it is obvious that the restoration of organic matter under dry-land conditions is extremely complicated. Under humid conditions it is practical to advise the farmer to grow legumes, use manure, return crop residues, grow green manuring crops, and rotate his land to grass. Whatever may be the real virtue of these practices, whether it be restoration of organic matter or nitrogen or something else, that farmer is wise who follows one or more of them. To advise these same practices for typical dry-land conditions is, to say the least, more a display of courage and hope than of judgment and wisdom.

After all, Are we dry-land agronomists correct in our assertion that next to water, organic matter is our most important soil problem? Have we not stressed too much the decline of organic content? Have we not over-emphasized the physical importance of organic matter in water relations, structure, and tilth?

Suppose we cease advocating to the farmers whom we serve that they must keep up the organic content of their soil if agriculture is to be permanent among them. They will not immediately suffer thereby for no efforts directed by us have been particularly fruitful to them so far. Suppose, instead, we attempt to discover what cultural practices of crop rotation or mechanical tillage will lead to a higher efficiency of rainfall and better structure and tilth conditions, regardless of organic content, and what cultural practices are conducive to desirable availability of nitrogen. In other words, suppose we determine what system of soil management is most profitable to the

immediate generation of farmers, guiding ourselves by our insight into the plant requirements for water, nitrogen, and good physical soil conditions. What will be the outcome?

Obviously, if we have given no thought to restoration of organic matter, nitrogen may decline. Our problem then becomes one of restoration of nitrogen. In a region where legumes are hazardous and the manure supply inadequate, one's thoughts turn naturally toward fertilizer. Will nitrogen fertilizer ever become practical in dry-land regions? The rapid strides in development of synthetic products, the reduction in transportation charges through production of higher analysis material, and increased efficiency and competition in the fertilizer industry are hopeful signs to the dry-land farmer that in the not too distant future nitrogen fertilizers may be sufficiently cheap that he can use them with profit.

The writer believes that one of the most important phases of the organic matter problem in the dry-land region is a thorough study of the possibilities of nitrogen fertilizer. Such study should, of course, be conducted over a period of years to include both wet and dry seasons, particularly on lands already depleted to the point where nitrogen is limited and always with the point in mind of eliminating the hazards of over-stimulation. In the meantime, it is highly important that all the reputed virtues of organic matter be submitted to rigorous tests. Should it transpire that the physical values of organic matter have been over-emphasized and that nitrogen can be maintained either by controlled azofication or through the use of fertilizers, the way is clear for continued development of dry-land agriculture along its present lines of power farming and extensive grain production.

## DISCUSSION[3]

The extent of the depletion of organic matter and of nitrogen incident thereto is one of the first questions that arises in a consideration of organic matter problems under dry farming conditions. A consideration of free fixation of nitrogen is another important phase of this subject. The sampling and analyses of soils, under various cultural treatments, for carbon and nitrogen in 1916 and again in 1928 at three of the western Kansas branch experiment stations furnish information upon these problems. The stations are located at Hays, Garden City, and Colby where the average annual precipitation is 22, 19, and 16.5 inches, respectively.

The study of carbon and nitrogen changes from 1916 to 1928 shows that the largest losses during the 12-year period occurred with rotation systems that included inter-tilled crops and that the smallest losses have been under continuous wheat culture, whether wheat after wheat, or wheat alternating with fallow.

The organic carbon losses in rotations varied from 8,000 to 14,000 pounds per acre and the nitrogen losses from 600 to 800 pounds per acre at the various stations. Under continuous wheat culture, including wheat and fallow, the carbon losses varied from 1,200 to 5,400 pounds per acre at Hays, and from 6,000 to 8,000 pounds per acre at Garden City and Colby. Where total nitrogen was comparatively low in 1916, the nitrogen losses under continuous wheat culture were in

[3]The writer wishes to acknowledge the help of W. L. Latshaw, Chemical Laboratory, Kansas Agricultural Experiment Station, in preparing the carbon analyses. The data upon which this discussion is based were accumulated in cooperation with Dr. P. L. Gainey, Department of Bacteriology, in a study of the free fixation of nitrogen.

most instances approximately 100 pounds per acre and there were cases of gains amounting to 20 and 60 pounds per acre. Small gains or losses are not significant because sampling and analyzing the same plats in 1927 and in 1928 lead to the conclusion that the approximate error in sampling amounts to 100 pounds per acre.

Although the data presented show that the nitrogen supply has been maintained in continuous wheat culture from 1916 to 1928 in some of the comparisons made and that organic carbon losses have been curtailed, it should not be inferred that losses of both organic carbon and nitrogen do not occur with continuous wheat when Buffalo grass sod is first brought under cultivation. In 1916, the soils at Colby had already lost 40% of the organic matter and 27 to 40% of the nitrogen, depending upon the number of years the soil had been cultivated. At Tribune, Kansas, a point further west, where the annual precipitation is 15 to 16 inches, the loss of organic carbon in surface soil of cultivated land has been 50% and the nitrogen loss 26% of the amount in virgin sod. In the case of both Colby and Tribune, the cultivated areas sampled had been cropped for about 20 years. Measurements from the period of 1916 to 1928, 12 years, show that the nitrogen supply has been maintained in continuous wheat culture in some of the comparisons made and that organic carbon losses have been greatly curtailed. Under inter-tilled cropping systems the losses of carbon and nitrogen have gone on without much abatement.

The foregoing discussion of nitrogen investigations in western Kansas has shown that there is evidence of free fixation in the dryland farming sections, there being either slight gains in nitrogen for a 12-year period or losses less than crop removal under systems of continuous wheat culture. Examinations of our western soils by Dr. Gainey have shown the presence of Azotobacter. These soils are neutral or slightly alkaline in reaction, which, together with a supply of energy-producing carbonaceous material, is the prime requisite for their nitrogen-fixing activities. The return of straw to the soil under favorable moisture conditions should therefore result in the fixation of more nitrogen. According to the natural forces governing the operation of the C-N ratio in the presence of sufficient nitrogen in the soil, there is less rapid decomposition of soil organic matter and hence some accumulation may take place. Sievers and Holtz[4] have quite clearly explained the operation of the C-N ratio and advocated that straw be supplemented with a commercial carrier of nitrogen in order that there may be an accumulation of organic matter and nitrogen in the soil.

Questions to be considered in the use of commercial nitrogen on our western dryland soils are: (1) over-stimulation of growth and thus subjecting a crop to greater drought injury, and (2) the possible development of sufficient nitrates from commercial nitrogen so as to inhibit nitrogen fixation and even cause losses of nitrogen. Experiments on the use of commercial nitrogen in connection with the return of straw to the soil are desirable.

Some doubt may arise as to the proper disposition of the heavy stubble and straw following the use of the combine wheat harvester following a bountiful crop. When the soil is dry, it is no doubt better practice, for the benefit of the immediate crop, to burn this straw and stubble, rather than to dry out the soil to a further extent by turning it under. Considering the effect of straw on free fixation of nitrogen and organic matter accumulation, it would seem better practice to let the stubble stand over winter and plow or list it in the spring, or if the stubble is free of weeds, to disk or cultivate lightly and fall plant in the stubble. Examinations of crop residues during the spring in the dryland farming sections of Kansas show that residues quickly decompose when covered with moist soil.

Soil samples were taken for nitrogen analyses from plats cropped continuously to kafir and to milo. The nitrogen losses were several times greater with these crops than with continuous wheat for the 12-year period investigated. We may infer that the cultivation of the soil during the spring and early summer, such as accompanies an inter-tilled crop, tends to accelerate nitrogen losses.

Since rotations including green manures were among the cropping systems studied, we have some data relative to this practice on soil nitrogen and organic carbon. At Hays a rotation consisting of corn, winter wheat, Canada peas for green manure, and barley resulted in a loss of 8,000 pounds of organic carbon per

[4]Wash. Agr. Exp. Sta. Bul. 206. 1926.

acre and of 200 pounds of nitrogen per acre. With continuous wheat or wheat and fallow, the loss of organic carbon was from 1,200 to 5,400 pounds and the loss in nitrogen from 80 to 140 pounds per acre for 12 years.

At Colby a rotation of milo, fallow, winter wheat, and Canada peas for green manure resulted in a carbon loss of 14,800 pounds per acre and a nitrogen loss of 720 pounds. The losses under continuous wheat ranged from 3,000 to 8,000 pounds and the nitrogen losses were 140 to 420 pounds except in one case of a gain of 40 pounds. Two rye green manure rotations at Garden City show losses of 6,400 pounds of carbon and 60 to 120 pounds of nitrogen compared with an 8,000-pound loss of carbon and a loss of 40 pounds of nitrogen under continuous wheat. With alternate wheat and fallow there were nitrogen gains. At all three points the green manure rotations have not increased organic matter and nitrogen in comparison with continuous cropping of wheat. The yields of a crop following green manure are as a rule no greater than that of a crop on fallow.

The same rotations at Hays and Colby with and without applications of straw supply some information as to the effect of straw on soil organic matter and nitrogen. The rotation is wheat, kafir, and fallow at Hays and wheat, milo, and fallow at Colby. Straw, where applied, is used as a top dressing on wheat at the rate of 2½ tons per acre. The crop yields have not been increased by this treatment, although there has been an appreciable effect on the soil nitrogen. By this application of straw, the carbon losses in the rotation were reduced only 200 and 300 pounds, and nitrogen losses were reduced 220 and 420 pounds, respectively, at Hays and at Colby.

Rotations at Hays and Colby include manure treatments and afford information regarding the effect of manuring on soil carbon and nitrogen. In the same rotation (wheat, kafir or milo, and fallow) used in determining the effect of straw, there are comparisons with manure at the rate of 3 tons and 12 tons applied on the kafir or milo stubble. At Hays, 3 tons of manure every third year reduced the carbon loss 50% and at Colby 40%. Twelve tons of manure reduced the carbon loss 60% at Hays and resulted in a gain of 1,200 pounds at Colby. In this same rotation, 3 tons of manure reduced the soil nitrogen loss 59% and 12 tons reduced it 83% at Hays. At Colby, 3 tons of manure reduced the nitrogen loss 50% and 12 tons of manure caused a gain of 60 pounds of nitrogen for the 12-year period. Here again crop yields were not increased by the manure treatments.

In Kansas, alfalfa and sweet clover are not considered dryland crops, hence we have not considered them in this discussion on organic matter problems under dry-farming conditions. There are no cultivated legumes well adapted for our western uplands therefore there is little hope of fixation of nitrogen by symbiotic bacteria. The problem of the extent to which we may rely upon free fixation for the future supply of nitrogen is of great importance to the Great Plains region in which is included a large part of the hard winter wheat producing area of the United States.—M. C. Sewell.

## 4. ORGANIC MATTER PROBLEMS IN IRRIGATED SOILS[1]

P. S. BURGESS[2]

Without doubt all soils are deficient in organic matter during their primary stages of formation, and later slowly accumulate this constituent chiefly from the dead residues of succeeding generations of plants. This process goes on until a condition of equilibrium finally is attained beyond which decomposition and accumulation largely offset each other and the amounts of organic matter and of nitrogen, if undisturbed by the hand of man, remain fairly constant. That climate, especially temperature and rainfall, is the predominating influence in determining the amounts of organic matter and of nitrogen at these points of equilibrium has been shown recently by Jenny (1).[3]

The cultivated soils of the arid and semi-arid regions are different from humid soils in that, while the climate has remained consistently hot and dry for thousands of years, soil-moisture relationships have been altered recently by artificial irrigation. Thus the natural equilibrium, in so far as organic matter is concerned, has been fundamentally changed even though no soil amendments may have been added and no crops grown. Simply supplying water to previously arid soils has brought this about. The organic-matter content of arid soils is very low in their natural state, varying from less than 0.1% up to 1.0% in exceptional cases. There is ordinarily no color change with depth in desert soils, the amount or organic matter occurring in the second and third foot often closely approaching that in the surface foot. As shown by Loughridge (2), small quantities of organic matter at depths of 8 feet or more are not unknown. Desert vegetation during past time has adapted itself to these conditions. It roots deeply and, during short rainy seasons, grows luxuriantly.

The first point which I wish to make is that organic matter is very low in arid soils in their natural state, and does not appear to be nearly as important quantitatively to most of our cultivated plants when these are subsequently grown under irrigation as is the case when these same plants are grown in humid regions. The first crops of grain sorghums, cotton, and alfalfa produced on virgin, desert soils after water has been applied, often give high yields and, with no artificial fertilization whatever, many of these soils remain productive for long periods. Under such a system of farming, which usually includes alfalfa on the land for possibly one-third of the time as this is a valuable cash crop, the organic matter content of the desert soil is often actually *increased* over a period of years, even though no definite attempt on the part of the farmer has been made in this direction and nothing but the below-ground parts of the crop plants have been returned to the soil.

[1]Paper read as part of the symposium on "Soil Organic Matter and Green Manuring" at the meeting of the Society held in Washington, D. C., November 22, 1928.

[2]Professor of Agricultural Chemistry, University of Arizona, Tucson, Arizona.

[3]Reference by number is to "Literature Cited," p. 977.

Many analyses of soils from old ranches long under irrigation have been made in our laboratories. These soils are very often higher in total nitrogen and in organic matter than are closely adjacent virgin soils, although the differences are never great. However, the importance of a definite attempt to maintain the organic matter supply is becoming realized more and more. As one Arizona farmer told me, "I know that organic matter is needed in my soils but it doesn't last from one year to the next." And this brings me to the next point which I wish to make, *viz.*, due to rapid decomposition in irrigated soils, brought about by high temperature and moisture conditions and usually by good aeration, it is almost impossible permanently to increase greatly an arid soil's organic-matter content by artificial means.

During the past four years our department has been interested in the fertilization of citrus trees (3), both in the Salt River Valley and on the Yuma Mesa. Soil samples to depths of from 5 to 8 feet have been drawn from a large number of bearing groves and studied in our laboratories. The ages of these groves vary from 5 to 35 years and some of them have received from 5 to 15 tons of corral manure per acre annually for long periods. Nevertheless, the total nitrogen content of these soils in no case exceeded 0.07% (usually less than 0.04%) and the organic-matter content was seldom greater than 1%. The citrus tree is a plant which is especially susceptible to an organic matter deficiency, yet the limited amounts of organic matter here recorded are apparently sufficient for optimum growth. That most crop plants require at least small quantities of organic matter for maximum development cannot be doubted, for all have become accustomed to its presence in soils during their age of adaptation to environment just as the higher animals have become accustomed to traces of substances in their food which we term vitamines. The small amounts of organic matter in desert soils, however, appear to furnish these decomposition products in sufficient quantities as well as supplying requisite amounts of available nitrogen. Contrary to the results of certain investigators, we find the alkali-soluble organic matter of arid, Arizona soils to be somewhat higher in total nitrogen than is generally reported for the organic matter in soils of the more humid sections of this country. The Utah Station has shown that while the different forms of organic matter added to soils tend to widen somewhat the C-N ratio of the humus, irrigation water always tends to narrow it, at least where applied to calcareous soils.

The nitrate-nitrogen content of many of our ground and stream waters is very much higher than the average for the United States. A series of analyses of these waters, together with soil analyses and a botanical examination of the flora of the water-sheds feeding these high-nitrate streams, has indicated that the conditions noted are due largely to the presence of wild, desert legumes. When such waters are used for irrigation purposes, the results are notably beneficial.

In certain irrigated soils, especially where shaded, the algal flora has been found to be especially rich at and near the surface. The rôle played by algae in soil economy is but imperfectly known. Waks-

man (4), in his review of the subject, states that, although probably unable to fix atmospheric nitrogen, algae may be able to do so by living symbiotically with nitrogen-fixing bacteria. He also calls attention to their ability to accumulate organic matter in soils. This may be of very great importance to irrigated soils, for Breazeale in our laboratories has shown that algal growth is the most readily available form of organic matter which he was able to find when applied to citrus seedlings grown in humus-free, acid-washed, silica sand. The enhanced growth due to this material was truly phenomenal. We are doing further work on this problem.

But how is the organic matter content of these irrigated soils to be maintained and possibly slightly enhanced? Three methods suggest themselves as follows: Keeping the land in alfalfa at least one-half of the time, the application of animal manures, and the plowing under of green-manure crops grown on the land.

Experience on our alfalfa farms has shown that, where this crop is grown more or less continuously, the organic matter and the nitrogen content of the soil are somewhat increased, but many farmers desire to grow other crops, such as cotton, corn, grain sorghums, lettuce, or cantaloupes, with only an occasional crop of alfalfa, so that this method of maintaining the organic-matter supply would not meet the general, popular demand.

The application of animal manures to Arizona soils has much to commend it. Hundreds of thousands of range cattle and sheep are brought into the irrigated valleys of Arizona every winter to be fattened for the Pacific Coast and eastern markets. Some are fed on cottonseed meal, cake and hulls, grain sorghums, and alfalfa hay in corrals or large feeding lots, and some are pastured to alfalfa and barley. Thousands of tons of manure accumulate in these corrals and, due to the aridity of the climate, its moisture content is very low, usually less than 10%.

On analysis, this material ordinarily runs at least twice as high in plant food ingredients as do eastern, wet manures. This dry manure can be purchased at from $1 to $3 per ton, depending on condition and location, the buyer doing the hauling. Experience has shown that an application of about 5 tons per acre is best for irrigated soils as smaller amounts "burn out" quickly. When applied at this rate it is worth about $3 per ton as valued by crop increases.

An experiment at the Utah Experiment Station (Bulletin 185, page 21) is of interest in this connection. Five tons of manure were applied to an irrigated soil each year over a period of 11 years. An analysis of the soil at the beginning and end showed the nitrogen content to have been increased by 1,370 pounds per acre which was 486 pounds more than actually had been added in the manure, although crops had been grown during this period and some leaching must have taken place. Active nitrogen fixation is thus indicated. They place the crop value of the manure at approximately $3.50 per ton as used in this experiment.

A very important factor in the application of manure to aird soils is that large numbers of beneficial bacteria are incorporated with it.

Recent work by the writer has shown that ammonification is low in many Arizona soils, nitrification is fair, while non-symbiotic nitrogen fixation is extremely active. Manure is especially rich in many of the ammonifying forms besides supplying energy materials for fixation.

The third method of maintaining an adequate organic matter supply is the turning under of green-manure crops. In Arizona, Hubam clover (*Melilotus alba annua*), sweet clover (*M. alba*), barley, and Whippoorwill cowpeas are the crops at present most commonly used, although the practice of green manuring is not as yet widespread. The first three ordinarily are used as winter catch crops to be plowed down on or before May 1, while the cowpeas and also sweet clover are grown during the summer season in orchards or vineyards or in preparation for a winter crop like lettuce. Annual varieties do best for short crops and the biennials for full year or summer growth.

From 1 to 2 tons per acre of dry matter above ground are usually produced by using these plants, but in western sandy or silty soils the roots should not be ignored. Studies at our experiment station have shown that more than one-half of the total weight of many plants is found below the surface and; as the roots penetrate to depths of 10 feet or more where drainage is good, the organic matter from this source is well distributed throughout the soil and must be of great value.

But the farmer is interested in the economics of the practice. It costs money to plow and put in a green-manure crop and additional irrigation water must also be purchased. Gravity water ordinarily costs about \$2 per acre-foot, while pumped water costs from \$6 to \$20 per acre-foot, depending upon the lift and the price of gasoline or electricity. It usually requires about 2 acre-feet of water to carry a cover crop during the winter season and much more if grown during the summer. The most reliable data available indicate that it costs from \$12 to \$15 per acre to grow a cover crop under these conditions exclusive of the plowing-under charge. With manure as easily obtainable and as cheap as it is in most parts of Arizona, it is doubtful whether cover crops at the present time can compete economically in the maintenance of soil fertility.

In comparing animal manures with green manure crops, it is interesting to note that the truck farmers of Arizona have found that no reasonable application of corral manure can take the place of a good alfalfa sod when turned under in preparation for lettuce, onions, or cantaloupes. These growers invariably rotate their land so that a 2- or 3-year-old alfalfa field is available for the truck crop. While we have done no work on this subject, two or three possible explanations present themselves. The first is distribution. Lettuce is ordinarily planted on the heavier soils and readily roots to depths of 4 or 5 feet where irrigated properly. The manure must, of necessity, be incorporated in the first foot of soil where oxidation is extremely active when moist, and practically non-existent when dried out at the surface between irrigations. Organic matter thus applied reaches the lower soil strata with difficulty. On the other hand, alfalfa roots of fairly large size penetrate deeply and, while weighing

less per acre than the manure application, they are more evenly distributed and probably decompose at a more uniform rate.

Second, with manure are added enormous numbers of micro-organisms, many of whose physiological functions under irrigation are at present imperfectly known. Plowing down an alfalfa sod, while doubtless increasing bacterial activity, does this with no direct addition of micro-organisms. And finally, the physical effects of deep-rooting plants like alfalfa on heavy soils should not be minimized, for here aeration and water penetration are very important factors.

No discussion of green manuring under irrigation would be complete without brief reference to the deleterious after effects of certain of the grain sorghums when their residues are plowed under as a source of organic matter. Milo, kafir, and hegari are extensively grown in the Southwest, both as grain crops and for ensilage; however, their culture often proves temporarily injurious to crops which immediately follow them in the rotation, the greater the residue plowed under, the greater the succeeding deleterious effects.

Breazeale (5) was the first to study this problem carefully. He concluded that the after effects noted were due to two things. First, to the formation of toxic bodies during the decomposition of the residue, and second, to a deflocculated condition of the soil caused by the poisoning and subsequent suppression of the bacterial flora which evolved carbon dioxide. This, in turn, created an equilibrium condition in the soil involving soluble calcium and sodium in which traces of sodium zeolite were formed, which, upon hydrolysis, produced a sufficient hydroxyl-ion concentration to cause deflocculation.

Recently, Conrad (6) has attributed the injurious after effects of sorghums to the high sugar content of these plants and, by means of fertilizer tests, has shown that there is apparently a competition for the available plant-food elements (especially nitrogen) in the soil during the initial decomposition between the sugar-splitting micro-organisms and the higher plants, with resulting injury to the latter. A depression in nitrification was also recorded. The remedial measures suggested by the work of Conrad and others consist in the removal of stalks and stubble, plowing immediately after harvest to give more time for decomposition, nitrogenous fertilization to succeeding crops, or growing legumes which apparently are but slightly affected. This, at the present time, is a real problem in our irrigated sections, for the grain sorghums are among our most important grain crops and should find a place in most rotations. Thus, there are forms of organic matter which may be deleterious as well as beneficial.

Lack of water is very often the factor which limits crop production in desert areas. The effect of organic matter in increasing the water-holding capacity of soils is too well understood to require discussion here, but its extreme importance for this purpose in arid soils should not be minimized. It is a well-established fact among the farmers of the Southwest that manure or other forms of organic matter are of special value where water is scarce. During dry seasons manure is also especially efficient in rendering crops more resistant to plant diseases.

The effect of organic matter on the availability of phosphates in calcareous soils is a subject which recently has received attention in our laboratories (7). It is fairly well established that when finely ground phosphate rock, or floats, is added to humid soils high in organic matter, as in the case of the fertile soils of the Middle West, it is readily rendered available, but when added to soils of low organic-matter content, as in the Piedmont section of the South, it is of little value. In the arid Southwest the same phenomenon is noticed as in the South but under a set of conditions very different from those existing in that section. While our soils are rich in total phosphorus and on occasion may contain an abundance of decomposing organic matter, no beneficial results are secured from the use of insoluble phosphates, although the effects of soluble phosphates are usually pronounced.

The soil atmosphere in humid regions, especially where organic matter is plentiful, is relatively high in carbon dioxide, and it has been proved that carbonic acid in the soil solution is a potent solvent for the tri-calcium phosphates. But we have shown that carbonic acid does not exist in the soil solution of calcareous or black alkali soils where free hydroxyl ions are always present in excess, for here the carbonic acid will react first with the more basic $Na_2CO_3$ and $CaCO_3$ to form the bicarbonates, rather than with the floats. Furthermore, our experiments have shown that, if carbon dioxide is artificially introduced into an aqueous suspension of a calcareous soil *heavily fertilized* with finely ground phosphate rock, the amounts of phosphorus dissolved and absorbed by growing plants are less than where pure distilled water alone is used as the solvent. This without doubt is due to the great excess of the common ion calcium which is brought into solution as the bicarbonate, depressing the solubility of the tri-calcium phosphate. If the common ion is added as gypsum, similar results are obtained.

In the heavy fertilization of lettuce with animal manures a poor, leafy, loose-headed crop almost invariably is obtained where soluble phosphates are withheld. In fact, a more marketable crop is often produced without manure than with it, due to this fact. Thus, the application of organic matter alone to arid, calcareous soils, while advisable from other considerations, will tend to decrease rather than to increase the availability of the insoluble soil phosphates. Thus, for most crops, additions of organic matter should be accompanied by soluble phosphate fertilizers.

Finally, brief consideration should be given to the importance of organic matter in the reclamation of alkali soils. Space does not permit of a discussion of the alkali-soil problem or of the detailed procedures followed in reclaiming alkali lands. Briefly, the usual method is to leach such soils with from 5 to 10 acre-feet of water in order to remove as much of the saline matter as possible (8). In heavy adobe soils, and where sodium zeolites are present, gypsum must be used to facilitate water penetration and under-drainage, but due to its low solubility (0.2%) it is impossible to rid soils completely of the last traces of black alkali by the use of this salt (9) and in

such soils 5 or 10 parts per million of alkalinity, figured as sodium carbonate, often seriously hinders water movement. For this reason we advocate fairly heavy organic-matter applications, preferably manure, at the end of the leaching period. Upon decomposition, quantities of carbon dioxide are given off which combine with these last traces of alkalinity to form sodium bicarbonate which is readily dissolved and removed in the drainage. The use of manure after leaching is also desirable because soils which have been leached continuously are usually found to be temporarily infertile, as much of the organic matter and practically all of the immediately available plant foods have been washed out with the alkali.

The study of organic matter decomposition in arid soils at present offers an intensely interesting field for study. Aside from the work of the Utah Experiment Station, little has been done. Others of our western experiment stations have made tests for ammonifcation, nitrification, and nitrogen fixation by the time-honored methods, but we really know little of the great families of bacteria, fungi, actinomyces, algae, and protozoa which are responsible for the profound chemical changes which take place with great rapidity in irrigated soils. The importance to fertility of these several classes of microorganisms probably varies with climate and with soil environment, and it is to be hoped that work along these lines may be attempted with arid soils in the near future.

## CONCLUSIONS

The organic-matter content of arid soils is very low in their natural states and, after reclamation, smaller quantities of this constituent appear to suffice than in the soils of humid regions. It has been found uneconomical to increase permanently the organic-matter content of irrigated soils to any large degree. This is due to the fact that decomposition processes, both biological and chemical, are extremely rapid owing to high temperatures, optimum moisture conditions, and good aeration.

The nitrate content of many of the ground and stream waters of desert regions is higher than would be expected. This is thought to be due to the presence of wild, leguminous vegetation on the watersheds which feed these streams.

The rôle played by algae in soils is but imperfectly known. Results have indicated that they may be of importance in accumulating organic matter in irrigated soils. They have been shown to be a valuable source of organic matter for plants.

There are three ways of maintaining the organic-matter content of irrigated soils, *viz.*, keeping the land in alfalfa at least one-half the time, the application of animal manures, and the plowing down of green-manure crops. Each of the three methods is discussed. As animal manure is fairly plentiful and cheap in the farmed sections of Arizona, this material is considered to be the most economical.

A brief discussion is given of the injurious after effects of the grain sorghums on crops following in the rotation. Remedial measures

are suggested. This is an important problem in the agriculture of the Southwest.

The effect of organic matter on the availability of the insoluble phosphates in calcareous soils has recently been studied in our laboratories and some of the results of this work are given.

In conclusion, the necessity for adding organic matter to alkali soils which are being reclaimed by leaching is pointed out and the reasons discussed.

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## DISCUSSION

The paper presented by Dr. Burgess has covered the problems of organic matter in irrigated soils very thoroughly. The conditions in Arizona and parts of the Southwest are more extreme than those found in the irrigated areas farther north. The long growing season with the possibilities of more than one crop per year introduces conditions which aggravate the problem of maintaining organic matter in the soil. On the other hand, these conditions may be taken advantage of in the maintenance of a greater amount of organic matter in the soil.

The advantages of both leguminous crops and barnyard manure are too well known and understood to more than mention. The scientific aspects of this problem have received a great deal of attention.

There is another phase of this question that the agronomist is called upon to answer and that is the economic. How can the farmer maintain a satisfactory production of all crops where nitrogen and organic matter are definitely limiting factors? Some sections can obtain sufficient barnyard manure either to maintain production at a satisfactory level or to supplement the amounts added through the use of legumes. Will the lowering of the price of nitrogenous fertilizers reduce the acreage of legumes?

Are we justified in recommending the growing of a leguminous crop as a green manure when the fertilizing value is very slightly, if at all, reduced by pasturing the crop? Can we find a way to make a profit out of leguminous crops when grown for their effect upon succeeding crops? These are some of the questions that are being asked by the farmers. The answers are to be found in a study of the farm organization. Some livestock enterprise is required if cover crops and green manures are to be grown at a profit other than that obtained from the increase in succeeding crops.

At present, the interest in organic matter in our arid soils is along the line of how this material can be best obtained and maintained. The conditions on each farm vary so that each farmer is confronted with the problem of working out a rotation or series of rotations that will best serve his particular case.

The livestock farmer converts a large part of the products raised into animal products and has a by-product of manure to assist in maintaining the organic matter in his soil.

The orchardist and special crop farmer is confronted with another problem. On some of our arid soils organic matter is not as important, seemingly, as on others. Yet we find the orchardist has been forced to seed his orchard to alfalfa, or where water is scarce he resorts to annual legumes and plows them under, practicing clean cultivation for a protion of the year. It is difficult to separate the effect of organic matter and nitrogen as the greater part of the crops grown to add organic matter to the soil have been legumes. The reasons for using a crop that will add organic matter and nitrogen to the soil are to improve the physical condition of the soil and to increase the yield of succeeding crops.

The farmer is interested in obtaining a satisfactory production at as low a cost as possible. The agronomist is called upon to find a means of maintaining this production and at the same time hold down the costs.

It does not seem possible at this time to solve the problem fully. The use of cover crops, catch crops, rotations, and manures has formed the background for our work in the maintenance of organic matter in the soil.

We are approaching a period where the amount of animal manures is greatly decreased. The tractor and truck have displaced horses as a means of transportation to a great extent. Coincident with the decrease in the use of horses has come the development of cheaper fertilizers. We have a problem before us in determining to what extent commercial fertilizers can be used as a source of nitrogen. We may find that our organic matter has served as a carrier of nitrogen and that by using commercial nitrogen as a substitute for some of the crops that have been grown for their fertilizing value we can increase the number of pay crops in our rotations. The work in the past has given a desirable background upon which to base a different use of organic matter as required by the change in farming methods.—G. R. McDole.

## 5. CHEMICAL AND MICROBIOLOGICAL PRINCIPLES UNDERLYING THE USE OF GREEN MANURES

S. A. Waksman

This paper appeared in the January, 1929, number of this Journal as the first of a series of three contributions by the author on the principles underlying the utilization of natural organic materials on the farm.—Editor's note.

# INFLUENCE OF ORGANIC MANURES ON THE CHEMICAL AND BIOLOGICAL PROPERTIES OF ARID SOILS[1]

J. E. Greaves[2]

It is not an uncommon thing in the arid west to fin dsoils containing in the surface-foot section sufficient potassium for the production of maximum crops for from 500 to 1,500 years, sufficient phosphorus for from 100 to 500 years, and sufficient nitrogen for only 30 to 50 years. Moreover, the second, third, and subsequent feet are equally rich in phosphorus and potassium, whereas the greater portion of the nitrogen is in the surface-foot section. Due to their scant vegetation and also to the rich, active, cellulose-decomposing ferments of the soil, their organic carbon content is low. Consequently, the great problem which confronts the tiller of these soils is two-fold, *viz.*, the supplying of nitrogen in sufficient quantities to meet the needs of the growing crop and not only to maintain but actually to increase the organic carbon of the soil. The quantity and nature of the organic material present determines the tilth, the water-holding capacity, the speed with which the essential plant foods are rendered available, and also the nitrogen supply of the soil. For these reasons we have given considerable attention to the influence of organic manures upon the chemical and biological properties of arid soils.

The principal investigations have been conducted on two soils. The first is typical dry-farm soil on the Nephi experimental dry-farm located about 5 miles south of Nephi on the north slope of the Levan Ridge. The soil has been derived from the weathering of the adjacent mountain ranges. These mountain ranges contain deposits of phosphates, potassium, and large quantities of gypsum. The soil of the farm is a clay loam and contains in the surface-foot section 4,100 pounds of nitrogen, 86,000 pounds of potassium, 7,000 pounds of phosphorus, 42,000 pounds of organic carbon, 69,000 pounds of magnesium carbonate, and 139,000 pounds of calcium carbonate.

The second soil is typical irrigated soil on the Greenville experimental farm located at Logan. This is a very productive calcareous loam of sedimentary origin, the surface-foot containing 4,900 pounds of total nitrogen, 2,700 pounds of total phosphorus, 60,000 pounds of total potassium, 434,000 pounds of acid-soluble calcium, and 132,000 pounds of acid-soluble magnesium.

These soils have been studied under laboratory, greenhouse, and field conditions during the past 15 years as to number and kind of bacteria, bacterial activities, nitrogen, and carbon content. The average for the number of bacteria, ammonifying, nitrifying, and nitrogen-fixing powers of the soil as determined on the field soil is given in Table 1. The virgin soil in each case is taken as 100%.

[1]Paper read as a "discussion" of Dr. Waksman's paper in the symposium on "Soil Organic Matter and Green Manuring" at the meeting of the Society held in Washington, D. C., November 22, 1928.

[2]Bacteriologist and chemist, Utah Agricultural Experiment Station, Logan, Utah.

TABLE 1.—*Bacterial activities of the Nephi dry-farm soil after receiving various treatments.*

| Treatment | Bacteria % | Ammonia % | Nitric nitrogen % | Nitrogen-fixers % |
|---|---|---|---|---|
| Virgin native grass....... | 100 | 100 | 100 | 100 |
| Continuous alfalfa........ | 143 | 108 | 105 | 225 |
| Continuous wheat........ | 145 | 75 | 123 | 1,320 |
| Rotation................ | 124 | 63 | 165 | 657 |
| Rotation, peas plowed under | 115 | 60 | 246 | 615 |

The rotation consisted of wheat, corn, peas, and potatoes. In one rotation all the plants were removed and in the other the peas were plowed under. In the continuous alfalfa the entire crop was removed, whereas in the continuous wheat much of the straw was permitted to remain upon the soil. There is a noticeable increase in the number of bacteria, nitrifying, and nitrogen-fixing powers in the cultivated soil due to the increased aeration, moisture content, and the returning of the plant residues to the soil on which bacteria feed.

When the ammonifying powers of the soil are considered, only a slight increase is noted due to the use of the green manures. The increase due to continuous alfalfa and continuous wheat is much greater. The effect of the alfalfa upon the nitrifying powers of the soil is also perceptible, thus showing that the alfalfa not only feeds closer on the nitrates of the soil but also stimulates it so it gives up its nitrogen more rapidly than the virgin soil. All the crops produce a measurable increase upon the nitric nitrogen content of the soil. This is most marked in the presence of the rotation in which the pea vines are plowed under. Here the nitric nitrogen which accumulated is nearly 2.5 times that in the virgin soil.

All of the treatments had a very marked effect upon the rate with which these soils gained in nitrogen. This was the case when the soil was incubated directly with mannite or when inoculated into Ashby mannite solution. The gain in the nitrogen in the continuous wheat-cropped soil is over 13 times what it is in the virgin soil. In the soil which had been in the rotation, the gain is six times as great as in the virgin.

These soils are low in organic carbon; consequently, the energy available to the non-symbiotic nitrogen fixers is limited, and one would expect that as this limiting factor in the nitrogen fixation is removed there would be greater gains in soil nitrogen. Both field and laboratory findings bear out this expectation. Limited surveys of these soils show that when continuously cropped to wheat there is an increase in their nitrogen-fixing powers.[3] This is sufficient to add approximately 30 pounds per acre annually to the soil and is probably due to the supply of energy furnished to the soil micro-organisms by the straw which is left on the soil due to the method of harvesting the grain. Adjoining constantly fallowed soils were not found to make these gains.

When the Nephi dry-farm soils were removed to the vegetation house and stored in pots with optimum moisture content, measurable

[3]GREAVES, J. E. A study of the bacterial activities of virgin and cultivated oils. Centr. für Bakt., Abt. II, 41:444–459. 1914.

gains of nitrogen were observed due to the action of non-symbiotic nitrogen fixers. The soil was kept in 2-gallon jars with optimum moisture content and varying kinds and quantities of plant residues. They were kept bare and received varying quantities of alfalfa, pea vines, and straw. The nitrogen content of the soil was determined at the beginning and after three years. The plant residues were applied at the beginning of the experiment and after two years; consequently, during the experiment, each soil received twice the quantity of plant residues given in Table 2. The average annual gain per acre, in addition to that supplied by the plant residue, is given in Table 2.

TABLE 2.—*Pounds per acre of nitrogen gained annually from the air by fallow soil receiving various treatments.*

| Treatment | Yearly gain in nitrogen, pounds per acre-foot of soil | Treatment | Yearly gain in nitrogen, pounds per acre-foot of soil |
|---|---|---|---|
| None.......... | 35 | 3 tons pea vines | 33 |
| 1 ton alfalfa.... | 161 | 4 tons pea vines | 0 |
| 2 tons alfalfa... | 304 | 5 tons pea vines | 0 |
| 3 tons alfalfa... | 123 | 1 ton straw | 77 |
| 4 tons alfalfa... | 254 | 2 tons straw | 74 |
| 5 tons alfalfa... | 43 | 3 tons straw | Loss |
| 1 ton pea vines. | 248 | 4 tons straw | Loss |
| 2 tons pea vines | 36 | 5 tons straw | Loss |

The average yearly gain per acre of nitrogen for the untreated soil was 35 pounds, a figure remarkably close to the one obtained in an earlier study. The application of plant residues greatly increased this. It was most effective in the case of the legumes, alfalfa, and peas, and less effective with the nitrogen-poor straw. In considering these results it must be remembered that this soil is low in nitrogen, hence another soil richer in nitrogen or even after fixation has continued in this soil so as to increase the nitrogen above a certain optimum for the nitrogen-fixing microflora may yield different results.

This soil, although an active nitrogen fixer, does not contain azotobacter, yet when azotobacter were inoculated into the soil they readily established themselves and after one year were easily recovered from soil kept in pots under vegetation house conditions.

A study of the native nitrogen-fixing microflora of the Nephi soil showed it to be composed of various organisms which have not heretofore been described. Nine of them were actimomyces, eight bacilli, eight micrococci, and one penicillum. All of these organisms fix appreciable quantities of nitrogen when grown in sterilized soil containing an appropriate carbohydrate.[4]

The results obtained when application of organic manures are made to the Greenville irrigated soils are just as remarkable. The results for the numbers, ammonifying, nitrifying, and nitrogen-fixing powers for the Greenville soil are given in Table 3. These are averages from many determinations made on carefully collected samples just as they came from the field.

[4]CARTER, E. G., and GREAVES, J. D. The nitrogen fixing micro-organisms of an arid soil. Soil Science, 26:179–197. 1928.

TABLE 3.—*Bacterial activities of Greenville soil in the presence of varying quantities of manure.*

| Treatment | Bacteria % | Ammonia % | Nitric nitrogen % |
|---|---|---|---|
| No manure............ | 100 | 100 | 100 |
| 5 tons manure.......... | 144 | 147 | 105 |
| 15 tons manure.......... | 177 | 188 | 486 |

All of the bacterial activities of the soil studied were greatly increased by the application of organic manures. There is a surprisingly close correlation between the effect of the manure upon the number of bacteria in the soil and its ammonifying powers, due to the greater proportion of the ammonifying organisms which grow upon the specific media used. After the soils had received the uniform treatment indicated in the table for a period of 11 years, they were carefully sampled to a depth of 3 feet and analyzed for nitrogen-fixing powers. The average results, representing from 12 to 18 determinations made on similarly treated plats, are given in Table 4.

TABLE 4.—*Milligrams of nitrogen fixed in 100 grams of soil, containing 2% of lactose, taken from fallow plats receiving varying quantities of water and manure.*

| Treatment | Milligrams of N fixed in various foot sections | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | Average |
| Unmanured.......................... | —1.5 | —2.7 | —2.0 | —2.1 |
| 5 tons manure.......................... | 3.8 | 2.1 | 0.2 | 2.0 |
| 15 tons manure.......................... | 5.5 | 5.4 | 3.1 | 4.7 |

The unmanured soil invariably lost nitrogen when incubated with 2% lactose. This was the case in each foot section, but was greater in the second and third than in the first. When 5 tons of manure had been applied to an acre annually for 11 years, the soil was changed from one which lost nitrogen on incubation to one which gained appreciable quantities. The addition of 15 tons of manure annually to each acre increased the nitrogen fixation over that in the soil receiving a yearly application of 5 tons to the acre. However, the actual gain per ton of manure is greater with the 5-ton application than with the 15-ton application.

The benefit exerted by manure upon the nitrogen-fixing powers of this soil is probably three-fold. (1) The manure carried to the soil a rich nitrogen-fixing and mineralizing microflora. These increase the acid production in the soil, which in turn renders available more phosphorus which is so essential to the rapid metabolism of azotobacter. (2) The plant residues in the manure when acted on by the cellulose microflora of the soil become a valuable source of energy to the nitrogen-fixers. (3) The addition of manure to this soil changed greatly its physical structure, thus increasing aeration within it. This would retard the growth of the anerobic nitrogen-fixers which are extremely wasteful of energy and would greatly accelerate the activities of the aerobic nitrogen-fixers. The total nitrogen contained in the variously treated soil was also determined. The average results are given in Table 5.

TABLE 5.—*Total pounds of nitrogen in 1 acre-foot (3,600,000 pounds) of soil, after receiving for 11 years varying quantities of organic manure.*

| Treatment | Pounds of nitrogen per acre in various foot sections 1 | 2 | 3 | Total |
|---|---|---|---|---|
| Unmanured | 3,758 | 3,226 | 2,218 | 9,202 |
| 5 tons manure | 4,310 | 3,444 | 2,818 | 10,572 |
| 15 tons manure | 4,702 | 3,627 | 3,121 | 11,450 |

During the 11 years, the soil receiving 5 tons of manure annually had received 884 pounds of total nitrogen in the manure. It had gained during this time 1,370 pounds, or 486 pounds more than had been received in the manure. It is highly probable that this annual gain of 44 pounds of nitrogen per acre was the work of non-symbiotic nitrogen fixers, the extra activity of which was made possible through the energy supplied in the organic material of the manure.

The soil receiving 15 tons of manure to the acre annually had received 2,653 pounds of nitrogen. It had gained 2,248 pounds of total nitrogen, which is 405 pounds less than was actually applied in the manure. The rapid nitrification which occurred in this soil probably rendered much of the nitrogen soluble and this was just carried below the third foot section and was not lost due to denitrification. One would conclude from an examination of the active nitrogen-fixing powers of this soil that it also was gaining nitrogen from the air due to the action of non-symbiotic nitrogen-fixing micro-organisms.

One year after the nitrogen determinations were made, that is, at the end of the 12-year period, the same plats were carefully resampled and analyzed for total organic carbon. The average results are given in Table 6.

TABLE 6.—*Organic carbon found in different foot sections of soil which for 12 years had received varying quantities of manure.*

| Treatment | Pounds per acre-foot (3,600,000) of carbon First foot | Second foot | Third foot | Total |
|---|---|---|---|---|
| No manure | 33,480 | 27,720 | 15,480 | 76,680 |
| 5 tons manure | 39,960 | 24,480 | 16,560 | 81,000 |
| 15 tons manure | 54,000 | 41,040 | 33,480 | 129,020 |

The percentage of organic material of the first, second, and third foot of the unmanured soil is 1.60, 1.33, and 0.74 (c x 1.724), respectively. The soil which has received 5 tons per acre annually for the past 12 years contains 1.91, 1.17, and 0.79% of carbon in the first, second, and third feet, respectively. The soil which had received 15 tons of manure yearly contained 2.59, 1.97, and 1.6% of carbon in the various foot sections.

Using Wolff's factor, c x 1.724, for converting the carbon into organic material, we find that the soil which had received annually 5 tons of manure per acre had gained 7,448 pounds of organic matter, which is 17.7% of the organic material applied to these plats during the past 12 years. Hence, in addition to the native organic carbon, which we have no method of estimating in these plats, the bacteria

have decomposed annually 2,879 pounds of organic material. This is very close to the 3,000 pounds which is often stated as being approximately the annual loss from a good arable soil. The soil which had received annually 15 tons of manure had gained 90,062 pounds of organic matter, which is 71.4% of the applied manure. Hence, the heavily manured plats were decomposing the applied organic material at the rate of 3,000 pounds per acre yearly, which is only 121 pounds more than was being decomposed in the lightly manured soil. The organic carbon content of this arid soil can be very materially increased by the application of organic manures; and the yearly loss of organic carbon is not much greater from heavily manured soils than from light manured soils, the decomposition being approximately 3,000 pounds annually. If we assume that the energy used by the nitrogen-fixing organisms in their metabolic activities all came from the 3,000 pounds of decomposed organic matter, there would be a fixation of 1 pound of nitrogen for each 70 pounds of organic material decomposed.

In conclusion, it can be stated that the application of organic manures to the irrigated and dry farm soils of Utah increase the ammonifying, nitrifying, and nitrogen-fixing powers of the soil. The gains in nitrogen, due to non-symbiotic nitrogen-fixers occurring under vegetation house conditions varied from 0 to 304 pounds per acre-foot of soil. The greatest gains occurred where legumes were used as the manure. The gain occurring in the soil under field conditions and attributable to non-symbiotic nitrogen fixation was 44 pounds per acre annually. Approximately 3,000 pounds of applied organic material was decomposed annually.

# 6. GREEN MANURING AND ITS APPLICATION TO AGRICULTURAL PRACTICES[1]

A. J. PIETERS AND ROLAND MCKEE[2]

The results secured from green manuring depend upon the rôle of organic matter in the soil. The previous papers have discussed the place of organic matter in the soil; and while the presence of nitrogen and the decay of organic matter offer scientific explanations for the value of green manures, their utilization by the farmer depends and will continue to depend on increased yields following the use of green manures. Fortunately, it can be shown that increased yields *do* follow the use of green manure and the knowledge of this fact is gradually extending, and with it the practice of turning under green crops. While this knowledge exists and the data at hand enable us to feel confidence in the broad statement that under favorable conditions green manuring will increase yields, it unfortunately is true that there is a great dearth of exact experimental data.

By green manuring as here discussed the writers mean the incorporating into the soil of green, or more or less mature crops, sown for this purpose. While a second crop of red clover turned under is, in effect, a green manure crop, this is a secondary, rather than a primary use of the crop.

Work has been done by many of the state experiment stations and by the United States Department of Agriculture, but we still await comprehensive, as well as exact data, as to the effect of green manuring on the permanent increase in the nitrogen and organic matter content of soils. Our information as to the yield increases following this practice is much fuller than is the evidence that permanent improvement of soil can be effected. Indeed in some cases, as on the poor Norfolk sands of Florida, such evidence as has been secured by the Florida Experiment Station points to the impossibility of permanent improvement. The organic matter oxidizes too rapidly.

Much of our information as to the yield increases due to green manuring comes from the experience of farmers, and while in a broad way such data are thoroughly reliable, they naturally lack the exactness to be expected in controlled experiments. In the present paper will be presented a general survey of the green manuring practices in the United States, together with some of the problems that need solution.

Green manuring was first practiced in Maryland and Virginia in the latter part of the eighteenth century but never spread widely. Today the use of green manure crops, or cover crops if you will, on the Atlantic Seaboard is mainly confined to orchards and truck crops.

[1]Paper read as part of symposium on "Soil Organic Matter and Green Manuring" at the meeting of the Society held in Washington, D. C., November 22, 1928.

[2]Agronomist, Forage Crops Investigations, U. S. Dept. of Agriculture, and Horticulturist, Foreign Plant Introduction, U. S. Dept. of Agriculture, Washington, D. C., respectively.

The general farmer of this region is beginning to use winter legumes but more especially in the southern part of this territory, in North and South Carolina. Here the practice has been encouraged by the county agents and the most convincing evidence of its value has been gathered from the experience of farmers. From Virginia to South Carolina, crimson clover, bur clover, and vetch used as green manures have effected increases in corn and cotton of from 100 to 500%. In some cases land so badly worn out as to be well nigh non-productive has been made to yield good crops. This part of the Coastal Plains is characterized by generally light soils, and the wider use of green manures would appear to depend mainly upon further education combined with a study of cultural methods and cover crops that may make the use of green manures more certain. Failures due to imperfect understanding of suitable crops and methods are still more frequent than they should be.

The growers of truck crops face a special problem, especially in the Norfolk region where some winter money crop may be grown. Where land is high priced it is desirable to use it as much as possible and a green manure crop is needed that will make considerable growth in a short time. The Virginia Truck Experiment Station has been active in this matter and has shown that green manures can replace, at least in part, the expensive and scarce stable manure. The success this station has had with turning under sorghum for potatoes illustrates the need for more fundamental studies on the relation between energy material turned under and available nitrate for the use of the bacteria.

Green manures are extensively used by the potato growers of New Jersey but the crop used is mainly rye, the growers depending on commercial fertilizers for their nitrogen

The pecan growers of south Georgia have found that green manure is essential in maintaining their groves in best condition.

The better orchardists in Virginia, Maryland, Delaware, and New Jersey grow cover crops which, as a rule, become green manure crops. In orchard work it is difficult to measure the effect of the green manure in dollars and cents, but the general experience of growers shows that in most cases the practice is not only profitable but necessary.

From the standpoint of the general farmer the greatest advances in green manuring have taken place in the cotton belt and in the corn belt. In the latter the striking feature has been the use of sweet clover for soil improvement. Practically all of the green manuring for corn in this section is done with sweet clover which on limed soil lends itself ideally to the purpose. Seeded with or on grain or in some cases with canning peas the sweet clover causes very small expense. Turned under for corn the fresh clover, rich in quickly available nitrogen, is an ideal fertilizer for the rapidly growing corn crop. Increased yields of 10 to 20 bushels an acre are common and this means, even in this area of good corn crops, an increase of from 25 to 50% or more. The value of green manuring with sweet clover has been abundantly proved, but there is room for plenty of study, not only to clear up interesting scientific questions, but to insure the best possible results

from the use of the crops. Willard and others have shown that there is a relation between the cutting of the first year's growth and the value of the crop the second year. The best time to turn under; the problem of successful fall plowing of the first year's growth; the relative value of turning under the spring growth, or the growth left after grazing; rapidity of decay of fresh and old growth; all of these problems need more careful study than has yet been given.

Not only is sweet clover proving its value on the good corn belt soils, it is increasing sugar beet crops in Colorado, reclaiming poor lands in southern Illinois, and sandy lands in Michigan. Perhaps no other crop has ever proved so potent an agency for soil improvement and crop increase through green manuring as has sweet clover.

In the cotton belt vetch, chiefly hairy vetch, is the crop that is making possible increased yields of corn and cotton on lands which without green manuring produce but indifferent crops. Alabama has been especially active in pushing the work with vetch and valuable data have been secured. Not the least valuable is the information that a relatively small crop of vetch has given better returns on cotton than a heavy crop. This is probably due to the fact that cotton needs to be planted early, but it may be suggested in this connection that nothing definite is known about the relation of the mass turned under and the net effect on the succeeding crop. It is true that the material turned under has been analyzed and the amount of nitrogen present determined. From the fact that 20 tons of green matter contain more nitrogen than 10 tons, it has been assumed that the former was more valuable than the latter. If, however, the nitrogen turned under is merely to be wasted it has no value to agriculture. It is merely suggested here that some crops may not be able to utilize advantageously the large masses of green matter turned under and that smaller amounts may often serve quite as good a purpose. If this should prove true the number of useful green manure crops might be increased because some do not now find favor because of the relatively small growth made by spring.

Besides vetch the Austrian winter pea is becoming popular in the South, more especially in Georgia. Its winterhardiness, exceeded only by hairy vetch, is an important factor in this popularity. The comparatively large size of the seed with the attendant relatively high cost of seeding and inadequate supplies of seed are limiting factors. This entire question of abundant and regular seed supplies is one of the most important practical questions in the study of green manuring in the South. Some southern authorities have insisted that the amount the farmer could pay for seed was limited to a relatively low figure and have advised against buying when the cost of vetch and pea seed exceeded such figures. While it is desirable for the southern farmer to get seed at as low a figure as possible, the stability of the supply and the stability of the price are also factors of importance and these will never be attained under the present system. Hairy vetch seed is an incidental crop in eastern Europe and when the crop is large and the price low the European farmer does not produce largely the next year. The consequence is a short supply and a high price.

A contract system with domestic producers would serve to balance supply and demand with a consequently more healthy and steady growth of the practice of green manuring. The already proved value of green manuring from New Jersey to Mississippi and elsewhere warrants the expenditures of much effort in solving all the problems of culture, of varieties, and of economics that will establish the practice on a firmer foundation.

In the southwestern United States in Arizona and California the citrus growers for years have been practicing green manuring. Here, as elsewhere, it has been found the most economical means of insuring the production of first quality fruit in quantity. The crops used and practices followed have changed somewhat as time has passed, but the early conclusions of the value of such crops has never changed. In the Salt River Valley of Arizona where the summer heat is intense and winters mild, a permanent cover of alfalfa in citrus orchards under irrigation has proved well suited to such conditions. Both summer and winter annual legumes are used to some extent. For the summer, cowpeas, sweet clover, and tepary beans are well adapted and for winter, field peas, common vetch, or sour clover.

In southern California citrus orchards, sour clover and common vetch are the crops most commonly used. These are early fall planted and are usually turned down in February. Much work has been done by the California Experiment Station in determining crops adapted and practices best suited to the needs of that region, but there are still many of the underlying principles of practices followed that never have been satisfactorily explained, nor is it yet certain that the most economical practice for all regions is being followed. Contrary to the practice in the Salt River Valley, it has not been found advisable in the coastal area of southern California to keep a permanent cover crop of alfalfa in citrus groves. The reason for the good results in Arizona and poor results in California has never been satisfactorily explained.

In the deciduous orchards of California the problem of green manuring has been more difficult than in the citrus area by reason of colder winter weather and, for the most part, lack of irrigation. Bur clover, grasses, and weeds grow naturally in the deciduous orchard regions and afford cover during the winter and green matter to turn down in the spring, but, without irrigation, the growth is light and usually considered of less value than a heavier crop with irrigation. A better crop for California deciduous orchards without irrigation and further work to determine the principles underlying the best practices of green manuring with irrigation in such orchards are needed.

In the apple orchards of Washington and Oregon and also in the Rocky Mountain states, the use of alfalfa as a permanent cover has increased in recent years until it now includes a large percentage of the total acreage. In some cases the alfalfa has superseded annual crops, or red clover, but in much of the area alfalfa is the only crop that has been grown. A critical study of alfalfa as a permanent cover in orchards is much needed. The advisability of using alfalfa as a

permanent crop in orchards in the regions mentioned has been clearly demonstrated, but many questions in connection with its use need to be scientifically answered. What are the factors favoring its use or limiting its use? What is the effect of the crop on the fertility of the soil when handled in different ways, and what factors are involved?

The truck crop grower of the West is faced with the problem of securing organic matter for his soils as is the truck grower in other parts of the country. Where crops are grown under field conditions and the ground is idle for a period of the year, green manure crops can and are being used in some areas. For the most part the green manure crops used for orchards, also, are the ones used for truck crops. Where intensive trucking is practiced with the land in constant use, organic matter must be supplied in the form of stable manure or crop plants in some form. The possibility of growing green manures for this purpose and the crops best adapted for the purpose is a matter that needs more attention.

The general farmer of the Pacific Coast states seldom grows a crop and turns it under solely for the purpose of green manure. The value of legume crops in rotations is recognized and vetch and clover are utilized in this fashion, but in such cases it is only the roots and stubble that are returned to the soil as fertilizer. In the Willamette Valley of western Oregon, where in early days wheat and oats were practically the only crops grown, the introduction of vetch and later clover in a rotation made possible greatly increased yields and diversified farming which has resulted in greater production and greater yields. Sievers and associates have shown that the rich grain lands of eastern Washington would benefit by an increase in organic matter content, but the problem of using green manures in this country is a difficult one, and has not yet been solved.

In reviewing the experimental work that has been done with green manures in the United States and the practices that are now followed, it is evident that much work remains to be done before many questions can be settled or answered. Some of these fall clearly in the field of chemistry, others physiology, and still others bacteriology or other specialized fields of biology. Some, however, are strictly agronomic problems or so directly involved with crop production that their solution can perhaps best be undertaken by the agronomist or carried on with his active cooperation. It takes but a hasty survey to indicate the wide scope this work must cover in order to answer the specific questions for the many soil types, various climatic conditions, and for each of the large number of agronomic and horticultural crops involved.

Not the least of the questions to which more attention should be paid is that of economics. By this we refer to practical rather than theoretical economics. Nearly all green manure crops can be used in other ways and green manure thus represents an investment the same as lime or fertilizers. Not only does it represent an investment in seed and labor, but it is the produce of the soil, a produce which might for example be fed to cattle rather than be turned under for another crop.

What is the relative advantage of each course? In some cases apparently definite figures may be quoted as when a crop of cowpeas could be made into hay which commands a definite price. The value of the hay plus the value of the increased cotton or corn secured from turning under the stubble only may be set against the value of the increase secured from turning under the entire crop. But even here no account is taken of the residual effect following the turning under of the entire crop.

In other cases it is difficult to arrive at any figures, and sometimes the feeding value of the legume is theoretical rather than real. When sweet clover is seeded with grain and turned under for corn some 8 or 10 inches of material, high in protein, is turned under which might have been grazed. If a farmer has at hand a number of cattle and has insufficient pasture, the value of the sweet clover for grazing may be considerable. If on the other hand, he has no cattle or has plenty of pasture no high value can attach to the sweet clover for that purpose. It is the practical rather than the theoretical value that must be considered. The same is true when considering the value of the manure that may be made from a given yield of legume. If there is a profit in the feeding of cattle apart from the manure, it may pay better to feed; but if the sole profit is to come from the manure, it can be shown that the farmer could better turn the crop under.

The economics of green manuring deserves consideration from farm economists, but in doing so account must be taken of the fact that the market value of hay or grazing is not always a perfect index of the value of a given crop in the field.

In order to bring to attention more definitely the more important problems of green manuring needing the attention of the agronomist, the following list of subjects is appended for consideration:

1. Green manure crop best adapted for different areas and conditions.
2. The time to plant for best growth, avoiding insects and disease.
3. Best time to turn under or otherwise dispose of material.
4. The rate of decomposition when turned into the soil at various stages of development.
5. The rate of decomposition when used as a surface mulch, both green and dry.
6. The relation to available plant food of incorporating mature dry plant residue (hay, etc.) into the soil vs. composting this and applying properly composted.
7. The relative effect on soil nitrates of different legumes.
8. The relation of different legumes to the following crop.
9. The relation to available plant food of leaving the green manure crop on the surface as a mulch vs. disking it into the soil or plowing it under.
10. The relative value of turning a summer green manure crop under in the fall or of leaving it on the ground until spring.
11. The value of a winter crop to follow a summer legume when the cash crop is not to be planted until the following spring.
12. The residual effect of various green manure crops when handled in various ways.

13. The accumulative effect of various green manure crops when handled in various ways.

14. The effect of green manures on physical condition of the soil.

15. The relation of green manures to chemical changes in the soil.

16. The relation of green manures to the increase or decrease of soil micro-organisms.

17. The effect of green manure crops on moisture supply and availability of moisture to cash crops.

18. The relation of green manure crops to leaching.

It is obvious that many of these problems must be solved specifically for each region, each soil type, and each cash crop, as well as taking into consideration both summer and winter legumes. Others are of more general application. The list could be extended. It is hoped, however, that these suggestions may interest those engaged in this line of investigation and stimulate a greater interest in this most important work.

## DISCUSSION

The authors of the preceding paper have called attention to the practice of using green manure crops in connection with truck crop production in Maryland and Virginia. While this practice has been followed more or less consistently for the last few years, there seems to be little definite data on the amount of increases that may be expected in the subsequent crop. In order to obtain some definite information on this point and also to determine the feasibility of substituting green manure crops for stable manure in truck crop production, the Virginia Truck Experiment Station undertook a series of experiments from which the following data are taken,

A block of land of Norfolk gravelly loam soil was selected on which to conduct this phase of the test. According to the best available records, it was under cultivation for a long period prior to the latter part of the last century. It then remained fallow until 1915 when it was again brought under cultivation. In 1924, the block was divided into six equal parts which were subdivided into eight plats each. The cropping system was so arranged that some green manurial crop in addition to the vegetables, on which records were taken, was grown on half of the plats and on the other half the green manure was omitted.

Potatoes were grown on portions of both the green manured and the non-green manured plats during the seasons of 1926, 1927, and 1928 and both cabbage and kale were similarly grown on other plats during the seasons of 1926 and 1927. Table 1 gives the average potato production records for the three seasons in which they were grown, Table 2 gives similar records for two seasons of cabbage, and Table 3 the records for two years of kale. All plats on which potatoes were grown received at the rate of 1,600 pounds of commercial fertilizer per acre analyzing 7% ammonia, 6% phosphoric acid, and 5% potash, The cabbage plats received 1,600 pounds per acre analyzing 9% ammonia, 6% phosphoric acid, and 5% potash. The kale plats received 1,200 pounds per acre analyzing 8% ammonia, 8% acid, and 3½% potash. The green manurial crop consisted of Amber sorghum on plat 1; soybeans on plats 2, 5, and 9; a mixture of sorghum and soybeans on plat 3; cowpeas on plat 4; corn sown broadcast on plat 6; and a heavy growth of weeds and grasses on plat 7.

The increases in yields of potatoes incident to the use of the various green manure crops in comparison to those obtained from plats similarly treated with commercial fertilizer but with the green manure omitted varied from 44.9% where corn was used as the source of the green matter to 61.8% where the natural growth of weeds and grasses was used. It should be stated that the natural vegetation mentioned consisted of a heavy growth of "crab grass" (*Digitaria sanguinalis*) with a rather liberal admixture of common weeds which usually spring up if the ground is left undisturbed after the potatoes are harvested in June.

TABLE 1.—*Potato yields 1926, 1927, and 1928.*

| Plat No. | Green manure crop used | Average yield in pounds per plat for 3 years: Green manure | No green manure | Increase: Pounds | % |
|---|---|---|---|---|---|
| 1 | Sorghum | 144.7 | 93* | 51.7 | 55.6 |
| 2, 5, 8 | Soybeans† | 143.1 | 93 | 50.1 | 53.9 |
| 3 | Soybeans and sorghum | 146.9 | 93 | 53.9 | 57.9 |
| 4 | Cowpeas | 143.7 | 93 | 50.7 | 54.5 |
| 6 | Corn | 134.8 | 93 | 41.8 | 44.9 |
| 7 | Natural vegetation | 150.5 | 93 | 57.5 | 61.8 |

*Average yield of the eight plats for three years.
†Average yield obtained from the three plats treated with soybean as the source of green manure.

The differences in yields between the plats treated with the various kinds of green manurial crops were examined biometrically according to Student's method of comparing plat pairs.[3]

The yields of the differently treated plats were paired with those of the adjacent soybean plats. Since in all cases the differences showed odds of less than 30 to 1, they were not considered significant. It will be noted in the various tables that the differences between the yields of the different plats treated with a green manurial crop were quite small.

While the percentages of increase obtained from the cabbage (Table 2) were not so great as those for potatoes, they are worthy of consideration.

TABLE 2.—*Cabbage yields, 1926 and 1927.*

| Plat No. | Green manure crop used | Average yield in pounds per plat for 2 years: Green manure | No green manure* | Increase: Pounds | % |
|---|---|---|---|---|---|
| 1 | Sorghum | 123.5 | 105.5 | 18.0 | 17.1 |
| 2, 5, 8 | Soybeans | 132.3 | 105.5 | 26.8 | 25.5 |
| 3 | Soybeans and sorghum | 129.0 | 105.5 | 23.5 | 22.3 |
| 4 | Cowpeas | 135.5 | 105.5 | 30.0 | 28.5 |
| 6 | Corn | 141.5 | 105.5 | 36.0 | 34.1 |
| 7 | Natural vegetation | 136.5 | 105.5 | 31.0 | 29.4 |

*Average yield of eight plats for two years. Mean of eight plats for three years = $105.5 \pm 4.114$.

With this crop sorghum as a source of green manure gave the smallest increase which was 17.1% over that obtained from the non-humus plats. Corn sown broadcast gave the greatest increase which was 34.1% over that obtained from the corresponding non-green manured plats.

TABLE 3.—*Kale yields, 1926 and 1927.*

| Plat No. | Green manure crop used | Average yield in pounds per plat for two years: Green manure | No green manure* | Increase: Pounds | % |
|---|---|---|---|---|---|
| 1 | Sorghum | 211.0 | 134.4 | 76.6 | 57.0 |
| 2, 5, 8 | Soybeans | 170.3 | 134.4 | 35.9 | 26.7 |
| 3 | Soybeans and sorghum | 187.0 | 134.4 | 52.6 | 34.8 |
| 4 | Cowpeas | 163.0 | 134.4 | 28.6 | 21.3 |
| 6 | Corn | 179.0 | 134.4 | 44.6 | 33.2 |
| 7 | Natural vegetation | 175.0 | 134.4 | 40.6 | 29.5 |

*Average of eight plats. Mean of eight plats for three years = $134.4 \pm 2.11$.

The greatest variation in the percentage of increases from the use of the green manurial crop were obtained with kale. Here sorghum as the source of green manure gave an increase of 57%, while cowpeas gave only 21.3% over the non-green manurial plats.

[3]LOVE, H. H., and BUNSIN, A. M., Student's method for interpreting paired experiments. Jour. Amer. Soc. Agron., 16: 1924.

The results of these tests confirm the findings of other experiments on the use of green manurial and cover crops as a factor in maintaining truck crop productivity on the coastal plain soils of eastern Virginia.[4] It is realized that considerable quantities of nitrogen are consumed in the decay of the large amounts of the green manures turned under; but granting this, it is evident that the grower can well afford to supply the deficiency thus caused in the form of commercial fertilizers in order to obtain the large yield increases recorded. It is recognized that there are important chemical, physical, and biological changes incident to the decay of the green manure in the soil, but it is not our intention to discuss these at this time.—T. C. JOHNSON.

[4]JOHNSON, T. C. Crop rotation in relation to soil productivity. Jour. Amer. Soc. Agron., 19:524–525. 1927.

# SEED CORN DRYING EXPERIMENTS[1]

C. M. HARRISON and A. H. WRIGHT[2]

Rarely, if ever, is seed corn when harvested in Wisconsin sufficiently dry to keep until planting time. Drying seed corn, consequently, is an important matter. Various methods are used. Many of these are unsatisfactory because they are either very expensive or produce poor quality of seed. To reduce cost and avoid poor quality, the bin method of drying seed corn has been introduced. This method dries by forcing heated air through ear corn in bins. The bins have a capacity of 25 to 50 bushels each. The depth of the corn is 5 to 7 feet. The direction of the air is alternated each 12 hours.

Because the bin method is rapidly replacing all other commercial methods of curing seed corn in Wisconsin, it has become very important to know the range of temperatures which can be used for drying, the rapidity of drying, and the degree of dryness which may be reached without damaging the seed.

An experimental bin drier was constructed and the heated air forced through ear corn with an electrically driven blower. An oven for heating the air was devised so that temperatures could be maintained without varying more than 3°C. The temperature readings were made of the air as it entered the bin.

Control samples were obtained by selecting random ears from each lot of corn. These were dried on hangers in a warm, well-ventilated room where they were allowed to remain until they contained approximately 12% moisture.

## TEMPERATURE EXPERIMENTS

The first or preliminary experiments were begun late in the season and the corn used had been injured to some extent by freezing weather. This caused uneven germination in all of the lots used, but because these preliminary experiments included details not contained in the later work the results are thought to be useful.

In the first series of experiments, six lots of freshly harvested corn were used. Each lot was tested for moisture content before drying began, and random ears for the control sample were reserved. Immediately afterward, the corn was subjected to rapid drying at desired temperatures. The total time of drying for each of the six lots was 120 hours. At the end of the drying period samples were

[1]Contribution from the Department of Agronomy, Wisconsin Agricultural Experiment Station, Madison, Wis. Published with the approval of the Director. Received for publication April 6, 1929.

[2]Graduate Assistant and Associate professor of Agronomy, respectively.

taken for testing. Tests were made of each lot for germination, seedling growth, and field performance.

The initial moisture content of the six lots varied from 16 to 27%. Different drying temperatures were used. Two lots were dried at 45°C, one lot at 50°C, one lot at 55°C, and two lots at 65°C. Details are given in Table 1.

TABLE 1.—*Effects of various drying temperatures on the germination of six lots of ear corn.*

| Lot No. | Initial moisture content % | Drying temperature, °C | Germination of bin-dried corn % | Germination with control at 25°C % |
|---|---|---|---|---|
| 1 | 16.0 | 45 | 91 | 90 |
| 2 | 23.0 | 45 | 69 | 65 |
| 3 | 25.3 | 50 | 60 | 70 |
| 4 | 22.4 | 55 | 64 | 75 |
| 5 | 22.0 | 65 | 18 | 55 |
| 6 | 27.4 | 65 | 18 | 65 |

In Table 1, lots 2 to 6 inclusive were considerably damaged by freezing weather before harvesting. The pronounced drop in germination as compared with lot 1, shown in control column, is accounted for by freezing damage.

The results show that a temperature of 45°C did not reduce the germination, that temperatures of 50° and 55°C caused considerable reduction in germination, and that a temperature of 65°C was pronouncedly harmful. The results also indicated that effects of temperatures are not governed by the initial moisture content of the corn.

Samples from each lot of the rapidly dried corn were planted in the greenhouse to test the seedling growth. The stands obtained were approximately in keeping with the germination test. All grains that grew produced plants that had an average vigor equal to the average of the control. Also, samples of each lot were planted in a field plat and compared in field performance with the controls. The observations made indicated that the grains which grew, regardless of the temperatures used in drying, produced plants which had an average vigor and development equal to the control.

## SECOND SERIES OF EXPERIMENTS

To supplement the first work, a second series of experiments was conducted with seed corn harvested in the fall of 1928 before any damage from freezing had occurred. This corn was sorted into mature, medium mature, and immature lots. Control samples were collected and dried in the same manner as in the first series of experiments. The total time of drying was 72 hours, but at the end of

each 12-hour period samples were taken for testing. Each sample thus obtained was tested for moisture and germination, but no tests were made on the seedling growth or field performance.

In this series of experiments 10 lots of freshly harvested corn were used. All of these were rather high in initial moisture content, ranging from 38 to 64%. Each lot contained 50 ears. Before drying began each lot was tested for initial moisture content and a composite sample reserved for slow drying to be used as a control. Of the 10 lots used, 3 were dried at 40°C, 3 at 50°C, 2 at 60°C, and 2 at 70°C. A summary of the results of this drying is given in Table 2.

TABLE 2.—*The effect on germination of rapidly drying ear corn at various temperatures.*

| Lot No. | Initial moisture content | Moisture after 72 hours drying | Drying temperatures in °C | Germination |
|---|---|---|---|---|
| | % | % | | % |
| 1 | 62.8 | 15.4 | 40 | 99 |
| 2 | 52.5 | 14.2 | 40 | 98 |
| 3 | 40.4 | 13.6 | 40 | 97 |
| 4 | 64.0 | 8.0 | 50 | 36 |
| 5 | 47.2 | 8.0 | 50 | 32 |
| 6 | 39.6 | 7.6 | 50 | 48 |
| 7 | 38.0 | 3.2 | 60 | 0 |
| 8 | 44.6 | 4.4 | 60 | 0 |
| 9 | 42.4 | 2.0 | 70 | 0 |
| 10 | 48.c | 2.0 | 70 | 0 |
| Control | 50.0(dried sl'wly) | 10.0 | 25 | 98 |

Table 2 shows that germination was not reduced when 40°C was used, regardless of the initial moisture content; that a drying temperature of 50°C for 72 hours caused serious damage; and that temperatures of 60° and 70°C for 72 hours completely destroyed germination.

The amount of moisture remaining in each lot of corn after 72 hours of drying varied according to the temperature used in drying. With a temperature of 40°C the moisture did not go below 13%, but with temperatures of 50°C and above the moisture content at the end of 72 hours was below 10% in each lot and went as low as 2% when 70°C was used. That the low germinations were due to high temperatures and not to excessive desiccation is indicated in Tables 3, 4, and 5.

Table 3 shows that corn when dried at 40°C germinated equally at all stages of desiccation; and that when dried 12 hours the germination was the same as when dried 24, 36, 60, or 72 hours. This indicates that when the temperature is not harmful, the amount of desiccation down to 13% does not affect germination.

TABLE 3.—*Effect on germination when corn was dried at 40°C.*

| Lot 1—moisture 62.8%, temperature 40°C | | | Lot 3—moisture 40.4%, temperature 40°C | | |
|---|---|---|---|---|---|
| Hours dried | Moisture % | Germination % | Hours dried | Moisture % | Germination % |
| 12 | 44.0 | 99 | 12 | 28.2 | 96 |
| 24 | 30.4 | 99 | 24 | 24.8 | 98 |
| 36 | 24.0 | 98 | 36 | 21.2 | 98 |
| 60 | 18.4 | 99 | 60 | 16.0 | 98 |
| 72 | 15.4 | 99 | 72 | 13.6 | 96 |

TABLE 4.—*Effect on germination when corn was dried at 50°C.*

| Lot 4—initial moisture 64%, drying temperature 50°C | | | Lot 6—initial moisture 39.6%, drying temperature 50°C | | |
|---|---|---|---|---|---|
| Hours dried | Moisture % | Germination % | Hours dried | Moisture % | Germination % |
| 12 | 37.6 | 99 | 12 | 28.8 | 80 |
| 24 | 27.4 | 92 | 24 | 23.6 | 86 |
| 36 | 19.2 | 64 | 36 | 16.0 | 26 |
| 48 | 10.4 | 50 | 48 | 9.2 | 48 |
| 60 | 8.4 | 38 | 60 | 8.0 | 38 |
| 72 | 8.0 | 32 | 72 | 7.4 | 48 |

The results given in Table 4 show that lot 4, which had an initial moisture content of 64% when dried at 50°C was injured very little by the first 12 hours of drying, but at each subsequent 12-hour period germination was pronouncedly reduced. In lot 6 the corn had a much lower initial moisture content and showed damage from the first 12 hours of drying. The second 12-hour period showed no increase in damage, but subsequent drying greatly reduced germination. In both of these lots the corn showed pronounced damage at relatively high moisture contents. This means that the injury was a temperature effect and was not caused by desiccation.

The relatively slight damage caused by the first 12 hours of drying, as shown in Table 4, was most likely caused by the evaporation of sufficient moisture to prevent the corn from reaching a critical

TABLE 5.—*Effect on germination when corn was dried at 60°C.*

| Lot 7—initial moisture 38%, drying temperature 60°C | | | Lot 8—initial moisture 44.6%, drying temperature 60°C | | |
|---|---|---|---|---|---|
| Hours dried | Moisture % | Germination % | Hours dried | Moisture % | Germination % |
| 12 | 20.4 | 92 | 12 | 28.0 | 99 |
| 24 | 13.2 | 0 | 24 | 18.0 | 4 |
| 36 | 8.0 | 6 | 36 | 11.6 | 0 |
| 48 | 4.8 | 0 | 48 | 8.0 | 0 |
| 60 | 4.2 | 0 | 60 | 4.6 | 0 |
| 72 | 3.2 | 2 | 72 | 4.4 | 0 |

temperature. This interpretation is also supported by the results given in Tables 5 and 6.

In Table 5 it is shown that when 60°C was used for drying very little damage was done during the first 12-hour period, but in subsequent periods, even though the moisture content was still rather high, the germination was nearly or entirely destroyed. This table also shows that the amount of damage during the first 12-hour period was proportional to the initial moisture content; and that lot 8, which contained 44.6% moisture after drying 12 hours, germinated 99%, while lot 7, which contained considerably less moisture, germinated only 92% after the first 12 hours. Like results were obtained when a temperature of 70°C was used, as shown in Table 6.

TABLE 6.—*Effect on germination when corn was dried at 70°C.*

| Lot 9—initial moisture 42.4%, drying temperature 70°C | | | Lot 10—initial moisture 48%, drying temperature 70°C | | |
|---|---|---|---|---|---|
| Hours dried | Moisture % | Germination % | Hours dried | Moisture % | Germination % |
| 12 | 26.4 | 58 | 12 | 30.8 | 86 |
| 24 | 8.4 | 0 | 24 | 10.0 | 0 |
| 36 | 5.2 | 0 | 36 | 6.8 | 0 |
| 48 | 3.2 | 0 | 48 | 3.2 | 0 |
| 60 | 2.0 | 0 | 60 | 2.8 | 0 |
| 72 | 2.0 | 0 | 72 | 2.0 | 0 |

Table 6 shows that corn when dried at 70°C was considerably damaged during the first 12 hours, and that germination was completely destroyed when the corn was dried 24 hours or more. This table also shows that the amount of damage done during the first 12 hours is influenced by the initial moisture content; that the lower the initial moisture, the greater the damage during the first drying period; that during the first 12 hours evaporation prevented, to a considerable extent, the corn reaching a critical temperature; and that damage to germination is caused by the high temperature and not by the rate of drying or amount of desiccation.

## EFFECTS OF EXCESSIVE DRYING

In connection with the work on the effects of different temperatures on seed corn, considerable information was also obtained on the effects of reducing seed corn to very low moisture contents.

In drying lot 1 of the first series of experiments at 45°C, it was found that after 24 hours of drying the moisture was less than 10% and that at each subsequent period of 12 hours the moisture gradually decreased until it was down to nearly 3% at the end of 120 hours. That the germination was not harmed by such excessive desiccation is shown in Table 7.

TABLE 7.—*Effects of excessive desiccation on seed corn with a non-harmful temperature of 45°C.*

| Drying time in hours | Moisture % | Germination % |
|---|---|---|
| 12 | 11.2 | 99 |
| 24 | 8.4 | 99 |
| 36 | 6.0 | 90 |
| 48 | 5.2 | 99 |
| 72 | 5.0 | 99 |
| 84 | 4.6 | 99 |
| 96 | 4.0 | 90 |
| 120 | 3.4 | 95 |

While some variation in germination is shown in Table 7, yet the results indicate that the amount of desiccation did not affect germination; and that regardless of how much the corn was desiccated, germination in the main remained the same.

To supplement the foregoing detailed experiment, samples of corn were obtained which had been dried to less than 10% by various methods. It was found that corn dried slowly for several months on hangers in heated rooms frequently contained a very low percentage of moisture at planting time. Three lots of such corn were obtained. Lot 1 was dried on hangers in a warm, well-ventilated basement. Lot 2 was dried by commercial seed corn growers who used artificial heat. Lot 3 was dried in a commercial bin drier. Corn from each of the foregoing lots had a moisture content of 4 to 8%. These lots were tested for germination and were also planted in field plat tests. In each case the germination was 97% or better and the field performance indicated no damage caused by excessive drying.

In testing seed corn for state certification, it was found that approximately 10% of the samples submitted had a moisture content of less than 10%. No field tests of these samples were made, but the germination averaged fully equal to the samples which contained more than 10% moisture.

## EFFECTS OF RAPID DRYING

While it is well known that the drying of seed corn in heated, well-ventilated rooms does not damage the seed, yet the advisability of drying the seed corn in only a few days is frequently questioned. The experiments on the effects of temperature on drying seed corn also furnished considerable information on the rate of drying. Table 3 shows that corn dried to 15% moisture or less in 72 hours was not damaged.

To supplement the detailed experiments, observations were made on the effect of rapid drying on seed corn in commercial bin driers.

During the last three autumns seed corn has been dried rapidly in commercial bin driers at temperatures around 40°C. The corn was dried down to around 12% in from 72 to 96 hours. Samples of corn thus dried have been tested for germination and have been grown in field plats. Germination has varied from 95 to 99%. When tested in the field and compared to corn dried slowly, the results indicated no damage from the rapid drying.

## SUMMARY


1. To insure good seed corn in Wisconsin, drying with heated air is necessary.

2. Ear corn when dried by forced warm air ventilation at temperatures of 40° to 45°C was not injured. Corn dried at 50°C was considerably damaged, and corn dried at 60°C was nearly all killed. Corn dried at 70°C was completely killed.

3. Seed corn dried to less than 10% moisture at non-harmful temperatures was not injured either in germination, seedling growth, or field performance. No damage resulted when the seed corn was dried to as low as 4% moisture.

4. When non-harmful temperatures were used, seed corn was not damaged regardless of the rapidity of drying. Corn dried to 12% moisture or less in 72 to 96 hours at temperatures of 40° to 45°C was not injured in germination, seedling growth, or field performance.

# CULTURAL TESTS WITH THE JERUSALEM ARTICHOKE[1]

ARTHUR ANDERSON AND T. A. KIESSELBACH[2]

The Jerusalem artichoke, *Helianthus tuberosus*, has been grown to a limited extent for many years as a forage and vegetable crop. Increased interest has been shown recently in its culture in view of the possible use of the tubers in the commercial production of levulose sugar. Shoemaker[3] in a recent paper, reviews the literature pertaining to the history and culture of the artichoke and discusses its uses and adaptation in this country. In the absence of local experience with this crop, a number of tests concerning its production were undertaken at the Nebraska Agricultural Experiment Station during the three-year period, 1925 to 1927.

Tubers were secured for planting in 1925 from the Bureau of Plant Industry of the United States Department of Agriculture. Due to the limited supply of tuber seed-stock, only one field plat was planted in 1925. Tubers for the 1926 and 1927 plantings trace back to those grown in 1925. The tests were enlarged in 1926 and 1927 to include comparisons as to date of planting, size of tuber seed piece, and spacing within the row. These tests were made in duplicate plats 160 feet long, which contained three rows spaced 3½ feet apart. The seed pieces were dropped in furrows, like potatoes, and covered 3 inches deep. The yields are based on the middle rows of duplicate plats. Four cultivations were given, the same as required for corn.

It has been found equally satisfactory to carry over the seed stock for planting the following season, either by storage in a vegetable cellar, as potatoes, or by leaving them in the ground until the following spring. (See Fig. 1.)

The yields of tubers and of tops, consisting of the stems and leaves, and the sugar resulting from complete hydrolysis of the carbohydrates of the tubers are reported for the three-year period, 1925 to 1927, in Table 1. Analyses showing the comparative food constituents of the tops and tubers are given in Table 2. The results per-

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[2]Agronomists. Acknowledgment is made to Director W. W. Burr for initiating these tests and to L. L. Zook, Agronomist of the North Platte Substation, E. M. Brouse, Superintendent of the Valentine Substation, and J. A. Holden, Superintendent of the Mitchell Substation, for supplying the field data from their respective substations. All sugar determinations and fodder analyses reported in this paper were made under the direction of Dr. M. J. Blish, Station Chemist.

[3]SHOEMAKER, D. N. The Jerusalem artichoke as a crop plant. U. S. D. A. Tech. Bul. 33. 1927.

taining to the date and rate of planting and the size of seed piece are summarized in Tables 3, 4, and 5.

## YIELD PER ACRE AND COMPOSITION

As a three-year average, 1925 to 1927, the moisture-free yields of tops and tubers (Table 1) were 1.87 and 1.51 tons per acre, respectively.

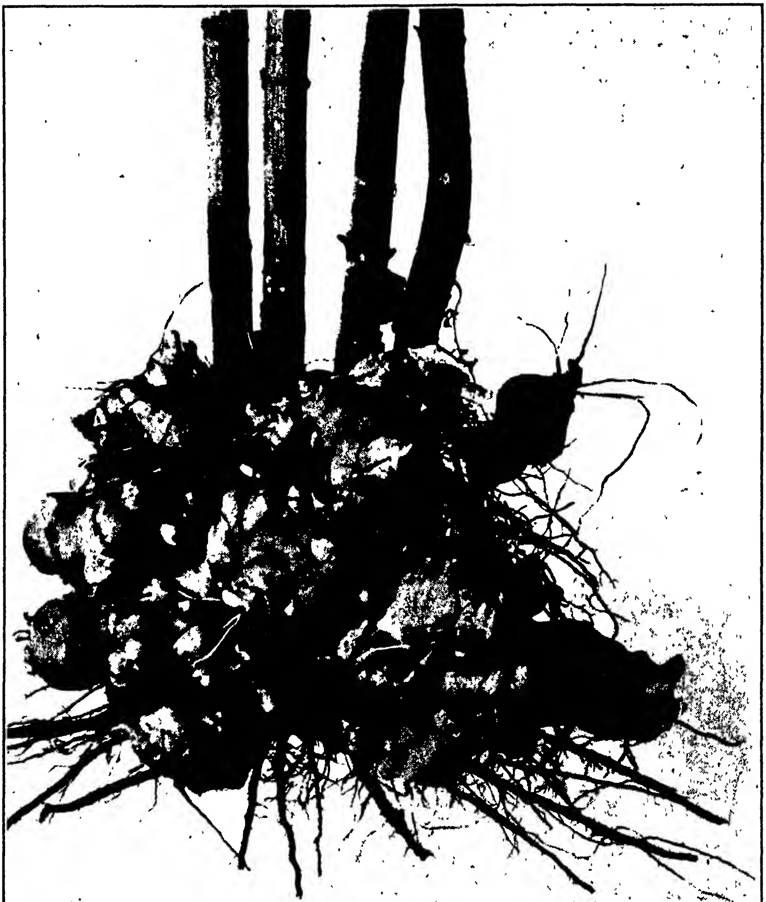

FIG. 1.—A typical hill of Jerusalem artichoke grown at Lincoln, Nebr., in 1927.

This average yield of tubers would have produced 1.07 tons of sugar, largely levulose, per acre.

During this three-year period the average moisture-free yield of the tops was 55% of the total yield. The seasonal variation in total

yield (tops and tubers) was less marked than for the yields of either tops or tubers alone. Based on the yield and fodder analysis of the tops and tubers in 1927 (Tables 1 and 2), the acre yields of 0.242 ton of ash, 0.266 ton protein, 0.477 ton fiber, 2.09 tons nitrogen-free extract, and 0.036 ton of fat were obtained. Of these constituents 69, 49, 89, 55, and 85%, respectively, was produced in the tops.

TABLE 1.—*Composition and yield of Jerusalem artichokes grown at Lincoln, Nebr., 1925–1927.**

| Year | Moisture content as harvested | | Sugar produced from tubers by hydrolysis | | Yield in tons per acre | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | As harvested | | Moisture-free | | |
| | Tops | Tubers | Moist basis | Dry basis | Tops | Tubers | Tops | Tubers | Sugar (tubers) |
| | % | % | % | % | | | | | |
| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) |
| 1925 | 58.2 | 74.4 | 18.1 | 70.6 | 5.99 | 4.58 | 2.50 | 1.17 | 0.83 |
| 1926 | 54.5 | 72.7 | 19.9 | 72.8 | 2.63 | 7.92 | 1.20 | 2.16 | 1.57 |
| 1927 | 70.5 | 79.9 | 13.4 | 66.7 | 6.45 | 6.00 | 1.90 | 1.21 | 0.81 |
| Average | 61.1 | 75.7 | 17.1 | 70.0 | 5.02 | 6.17 | 1.87 | 1.51 | 1.07 |

*Average date of planting March 31. Seed pieces (50 per pound) planted 14 inches apart in 42-inch rows.

TABLE 2.—*Comparative feed constituents of the tops and tubers of Jerusalem artichokes grown at Lincoln, Nebr., in 1927.*

| Portion of plant | Moisture content when harvested | Constituents (moisture-free basis) | | | | |
|---|---|---|---|---|---|---|
| | | Ash | Protein | Fiber | Nitrogen-free extract | Fat |
| | % | % | % | % | % | % |
| Tops...... | 70.5 | 8.78 | 6.91 | 22.25 | 60.45 | 1.61 |
| Tubers..... | 79.9 | 6.19 | 11.18 | 4.45 | 77.73 | 0.45 |

The average comparative moisture-free yields during this same period for sunflowers and corn grown in rows for silage and orange sorghum grown in close drills for hay were 2.26, 2.96, and 3.56 tons per acre, respectively.

In contrast to the field yield of 4.58 tons of tubers per acre obtained at Lincoln in 1925, with a sugar content of 18.1% in terms of total reducing sugars produced by acid hydrolysis of the tubers, the following results were secured at the various substations in the state: North Platte, 1.56 tons of tubers per acre with a sugar content of 12.7%; Valentine, 10.0 tons per acre with a sugar content of 13.6%; and Mitchell, 13.6 tons of tubers per acre with a sugar content of 15.5%. The artichokes at Valentine and Mitchell were grown under sub-irrigated and irrigated conditions, respectively.

## RELATION OF PLANTING DATE TO YIELD

The comparative moisture-free yields of tubers and tops secured during a two-year period from planting at four different dates in the

spring (Table 3) were as follows: March 22, 3.24 tons per acre; April 7, 3.30 tons; April 17, 3.48 tons; and April 30, 3.11 tons.

TABLE 3.—*The relation of planting date to the yield of Jerusalem artichokes, 1926 and 1927.**

| Average date planted | Height of stalk, inches | Yield in tons per acre | | | | | |
|---|---|---|---|---|---|---|---|
| | | As harvested | | | Moisture-free | | |
| | | 1926 | 1927 | Average | 1926 | 1927 | Average |
| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
| | | | Tubers | | | | |
| March 22...... | — | 7.92 | 6.00 | 6.96 | 2.16 | 1.21 | 1.69 |
| April 7........ | — | 8.33 | 6.33 | 7.33 | 2.27 | 1.27 | 1.77 |
| April 17....... | — | 7.66 | 7.22 | 7.44 | 2.09 | 1.45 | 1.77 |
| April 30....... | — | 6.60 | 6.27 | 6.44 | 1.80 | 1.26 | 1.53 |
| | | | Tops | | | | |
| March 22...... | 62 | 2.63 | 6.45 | 4.54 | 1.20 | 1.90 | 1.55 |
| April 7........ | 62 | 2.87 | 5.96 | 4.42 | 1.30 | 1.76 | 1.53 |
| April 17....... | 63 | 2.65 | 7.47 | 5.06 | 1.21 | 2.20 | 1.71 |
| April 30....... | 60 | 2.24 | 7.22 | 4.73 | 1.02 | 2.13 | 1.58 |
| | | | Total (Tubers and Tops) | | | | |
| March 22...... | — | 10.55 | 12.45 | 11.50 | 3.36 | 3.11 | 3.24 |
| April 7........ | — | 11.20 | 12.29 | 11.75 | 3.57 | 3.03 | 3.30 |
| April 17....... | — | 10.31 | 14.69 | 12.50 | 3.30 | 3.65 | 3.48 |
| April 30....... | — | 8.84 | 13.49 | 11.17 | 2.82 | 3.39 | 3.11 |

*Seed pieces (50 per pound) planted 14 inches apart in 42-inch rows.

The highest yield of tubers was secured on the second and third planting dates and that of the tops on the third planting date. These data, though perhaps not very conclusive, suggest that there may be considerable range in planting date during the latter part of March and the first half of April without materially affecting the yield. In general, the normal season for planting spring grains is the proper time to plant artichokes.

## RELATION OF RATE OF PLANTING TO YIELD

Spacing of the seed pieces, 7, 14, and 21 inches apart in 42-inch rows resulted in total moisture-free yields (tubers and tops) of 3.16, 3.33, and 3.24 tons per acre, respectively, as a two-year average (Table 4). Corresponding yields of tubers alone were 1.77, 1.72. and 1.69 tons per acre. The slight increase in yield of tubers from the 7-inch spacing was more than offset, however, by the additional amount of tubers required for planting. The tubers produced in the 7-inch spacing were also distinctly smaller.

## RELATION OF THE SIZE OF SEED PIECE TO YIELD

Three sizes of seed pieces were planted in a comparative test to determine the effect, if any, upon yield (Table 5). These sizes involved 50, 25, and 10 seed pieces per pound, the larger size usually consisting of 10 average tubers per pound.

TABLE 4.—*The relation of planting rate to the yield of Jerusalem artichokes, 1926 and 1927.**

| Distance apart in row, inches (1) | Height of stalk, inches (2) | Yield in tons per acre, As harvested, 1926 (3) | As harvested, 1927 (4) | As harvested, Average (5) | Moisture-free, 1926 (6) | Moisture-free, 1927 (7) | Moisture-free, Average (8) |
|---|---|---|---|---|---|---|---|
| | | | Tubers | | | | |
| 7 | — | 7.73 | 7.13 | 7.43 | 2.11 | 1.43 | 1.77 |
| 14 | — | 7.78 | 6.56 | 7.17 | 2.12 | 1.32 | 1.72 |
| 21 | — | 7.76 | 6.26 | 7.01 | 2.12 | 1.26 | 1.69 |
| | | | Tops | | | | |
| 7 | 52 | 2.23 | 5.98 | 4.11 | 1.01 | 1.76 | 1.39 |
| 14 | 61 | 2.94 | 6.34 | 4.64 | 1.34 | 1.87 | 1.61 |
| 21 | 64 | 2.79 | 6.16 | 4.48 | 1.27 | 1.82 | 1.55 |
| | | | Total (Tubers and Tops) | | | | |
| 7 | — | 9.96 | 13.11 | 11.54 | 3.12 | 3.19 | 3.16 |
| 14 | — | 10.72 | 12.90 | 11.81 | 3.46 | 3.19 | 3.33 |
| 21 | — | 10.55 | 12.42 | 11.49 | 3.39 | 3.08 | 3.24 |

*Average date of planting April 11. Seed pieces (50 per pound) planted in rows 42 inches apart.

TABLE 5.—*The relation of size of seed piece planted to the yield of Jerusalem artichokes, 1926 and 1927.**

| Size of seed piece planted† (1) | Height of stalk, inches (2) | Yield in tons per acre, As harvested, 1926 (3) | As harvested, 1927 (4) | As harvested, Average (5) | Moisture-free, 1926 (6) | Moisture-free, 1927 (7) | Moisture-free, Average (8) |
|---|---|---|---|---|---|---|---|
| | | | Tubers | | | | |
| Small......... | — | 7.78 | 6.56 | 7.17 | 2.12 | 1.32 | 1.72 |
| Medium....... | — | 8.43 | 6.57 | 7.50 | 2.30 | 1.32 | 1.81 |
| Large......... | — | 8.40 | 7.40 | 7.90 | 2.29 | 1.49 | 1.89 |
| | | | Tops | | | | |
| Small......... | 61 | 2.94 | 6.34 | 4.64 | 1.34 | 1.87 | 1.61 |
| Medium....... | 58 | 2.72 | 5.67 | 4.20 | 1.24 | 1.67 | 1.46 |
| Large......... | 56 | 2.50 | 5.36 | 3.93 | 1.14 | 1.58 | 1.36 |
| | | | Total (Tubers and Tops) | | | | |
| Small......... | — | 10.72 | 12.90 | 11.81 | 3.46 | 3.19 | 3.33 |
| Medium....... | — | 11.15 | 12.24 | 11.70 | 3.54 | 2.99 | 3.27 |
| Large......... | — | 10.90 | 12.76 | 11.83 | 3.43 | 3.07 | 3.25 |

*Average date of planting April 11. Seed pieces planted 14 inches apart in 42-inch rows.

†Small, medium, and large seed pieces consisted of 50, 25, or 10 pieces per pound, respectively. The larger size was in most cases an average sized tuber.

As a two-year average there was a decrease in total moisture-free yield (tubers and tops) of 0.08 ton per acre, with an increase in seed-piece size from the smallest to the largest. This difference is well within the limits of the experimental error, but in view of the fact that there was an increase in yield of 0.17 ton per acre in the case of the tubers and a decrease of 0.25 ton in the yield of tops, these data

suggest that conditions were more favorable for tuber development in case of the larger seed piece. The increases in yield from medium and large seed pieces were not sufficient, however, to offset the extra tubers required for planting. Should seedbed conditions be unfavorable, the larger seed piece might prove advantageous.

## SUMMARY

As an average for three years, 1925–1927, the Jerusalem artichoke yielded 6.17 tons of tubers and 5.02 tons of tops per acre, or a total yield of 11.19 tons per acre. Reduced to a moisture-free basis these yields were 1.51, 1.87, and 3.38 tons per acre, respectively. Comparable moisture-free forage yields of sunflowers and corn planted in rows for silage and orange sorghum grown in close drills for hay were 2.26, 2.96, and 3.56 tons per acre, respectively.

The three-year average yield of 6.17 tons of fresh tubers per acre would produce 1.07 tons sugar which is 17.1% of the tuber weight.

Results based on a two-year average suggest that there may be considerable range in planting date during the latter part of March and the first part of April without materially affecting the yield.

As a two-year average the highest total yield per acre was secured from spacing the seed pieces 14 inches apart in the row. Seven-inch spacing produced a slightly higher acre yield of tubers, but they were noticeably smaller in size.

As a two-year average, there was very little difference in total yield from planting small, medium, or large seed pieces. There was, however, an increase of about 10% in the yield of tubers and a decrease of 15% in the yield of tops as the number of seed pieces per pound was reduced from 50 to 10.

Spacing seed pieces of this smallest size 7 inches apart in the row would require approximately 425 pounds of tubers per acre. The highest net yield of tubers (gross acre yield less tubers planted), however, was obtained from spacing the small tuber pieces 21 inches apart.

# COMPARATIVE FREQUENCY OF DEFECTIVE SEEDS AND CHLOROPHYLL ABNORMALITIES IN DIFFERENT VARIETIES OF CORN FOLLOWING SELF-FERTILIZATION[1]

C. M. WOODWORTH[2]

## INTRODUCTION

When a variety of corn is self-fertilized many kinds of abnormalities appear with more or less frequency. This seems to be the common experience of all who have self-fertilized corn. The most common abnormalities observed are defective kernels on the selfed ears and chlorophyll deficient types of seedlings. In the ordinary variety propagated by natural crossing few such abnormalities are found, due to the fact that they are covered up by the normal dominant type, and only occasionally does a gamete carrying an abnormal recessive type unite with another gamete carrying the same abnormal recessive type. It appears, therefore, that cross-fertilization, such as occurs in corn under natural conditions, protects or shields these germ plasm changes from the rigorous action of natural selection, and hence causes or permits them to accumulate in the variety in the heterozygous condition.

In the corn breeding program at the Illinois Agricultural Experiment Station, the plan is followed of selfing a large number of ears of a given variety so that an extensive amount of material is available for study and test, on the assumption that the greater the number of ears studied the better the chances of obtaining strains of superior merit. For selfing, plants are chosen that are apparently healthy, vigorous, erect, and normal in every way. At maturity, the selfed ears are harvested only from the erect, vigorous, apparently healthy plants that are maturing normally. Considerable selection is therefore exercised, not only at the time of selfing but also at the time of harvest. The purpose is to start the breeding work with the best material in the variety. Nevertheless, a relatively high proportion of the ears are found to segregate for seed and seedling abnormalities. Whether in random plant and ear selection this proportion would be increased, has not been determined.

[1]Contribution from the Division of Plant Breeding, Department of Agronomy, University of Illinois. Published with the approval of the Director of the Station. Received for publication April 15, 1929.

[2]Associate Chief in Plant Breeding.

## VARIETIES STUDIED

Observations are presented here on three varieties of corn that have been selfed and studied as described above, namely, Reid Yellow Dent (Station strain), Illinois High Yield, and Illinois Two Ear. The particular strain of Reid Yellow Dent used has been grown on the experiment station farm for a long time. It has always been carried on by mass selection, and since about 1920 seed ears have been selected according to the plant, ear, and germinator selection plan previously outlined by the author (6).[3] This strain has likely been considerably improved within recent years particularly in disease resistance.

The Illinois High Yield corn was developed by 10 years' selection for yield according to the ear-to-row system (5). The Illinois Two Ear strain was produced by selection since 1904 for stalks bearing two or more ears. For 18 years the selection was carried on under the ear-row breeding plat system in which, after the first three years, the seed was systematically chosen from the higher yielding rows. While the proportion of two-eared stalks has varied greatly from season to season, the average for the last 10 years was 60%. This variety is now the best yielder in the variety test conducted on the Agronomy South Farm (2). Since 1922, both the Illinois High Yield and the Illinois Two Ear strains have been continued by the mass selection method used for Reid Yellow Dent. There are in this comparison, therefore, (a) a variety that has been carried on by mass selection, (b) a variety that has been developed by the ear-row system, and (c) a variety that has been developed by combining ear-row selection for yield with selection for tendency to bear two or more ears per stalk.

## METHODS

The ears of Illinois High Yield and Illinois Two Ear were sorted into two classes on the basis of the characters listed under general appearance on the utility corn score card (4). Class 1 contained ears that were heavy, lustrous, with good kernel type, and bright shank attachment, and class 2 contained ears that were not first class in one or more of these characteristics. Into class 2 were also placed all ears that were apparently segregating for observable defective seed types.

Ears of Reid Yellow Dent were sorted into three classes on the same basis as those of the other two varieties. Classes 1 and 2 were the same as classes 1 and 2 described above, and class 3 contained undesirable ears that would ordinarliy be discarded, ears light in weight, dull, starchy, diseased, or with shredded shanks. Ears of Illinois High Yield and Illinois Two Ear were rigorously selected at harvest time

[3]Reference by number is to "Literature Cited," p. 1014.

and no ears were saved that would belong in class 3. The presence of observable defective seeds was not considered when the ears of Reid Yellow Dent were classified on the basis of appearance.

The types of defective seeds observed were cases in which the endosperm failed, for one reason or another, to reach normal development. When the ears were shelled, however, and the kernels examined, many instances of germless seeds and miniature germs were found.

The test for seedling abnormalities was made by planting seeds of each ear in sand benches in the greenhouse. In the case of Reid Yellow Dent, 15 seeds of each ear were tested, and 25 seeds in the case of the other two varieties. It is believed that the larger number is better than the smaller for this purpose, as on a mere chance basis it would be expected that the larger the number of seeds tested the better the chances of bringing out instances of segregation.

## RESULTS

### COMPARISON OF VARIETIES

The results of this study bring out many points of interest (Table 1). The High Yield strain has not only a very high percentage of ears with defective seeds, but also a very high percentage of ears segregating for chlorophyll deficiencies. Reid Yellow Dent and Two Ear show very little difference in percentage when both defective seeds and chlorophyll deficient seedlings are combined, though Two Ear is the lower in percentage of abnormal seedlings. At present no adequate reason suggests itself to account for this difference between the High Yield and the other two varieties. Hayes and Brewbaker (3) also found wide differences in percentage of ears giving chlorophyll deficient seedlings in the corn varieties they studied, Minnesota 13 giving 39.4%; Rustler, 11%; and Northwestern Dent, 10.4%.

### GENERAL APPEARANCE OF EARS AND PERCENTAGE OF ABNORMALITIES

There appears to be some relation between general appearance of ears and percentage of defective seeds in Reid Yellow Dent. As stated above, the ears of this variety were sorted into three classes on the basis of their general appearance, no attention being paid at the time to the presence of observable defective endosperm types. It is interesting to note (Table 2) that class 1, containing the best ears, had the smallest percentage of ears with defective kernels. However, while the percentage is higher in class 2 than in class 1, it is lower in class 3 than in class 2.

TABLE 1.—*Comparison between varieties of corn as to percentage of seed and seedling abnormalities following self-fertilization.*

| Variety | Total number of ears | Ears segregating for defective seeds Number | % | Ears segregating for chlorophyll deficiencies Number | % | Ears segretating for both types of abnormalities % | Ears segregating for either one or both types of abnormalities % |
|---|---|---|---|---|---|---|---|
| Reid Yellow Dent.... | 818 | 32 | 3.9 | 100 | 12.2 | 0.85 | 15.3 |
| Illinois High Yield.... | 321 | 96 | 29.9 | 93 | 28.9 | 13.08 | 45.8 |
| Illinois Two Ear..... | 209 | 15 | 7.2 | 21 | 10.0 | 0.48 | 16.7 |

TABLE 2.—*Comparison of ear classes based on physical appearances to percentage of seed and seedling abnormalities following self-fertilization.*

| Variety | Class based on general appearance of ear | Total number of ears | Ears segregating for defective seeds Number | % | Ears segregating for chlorophyll deficiencies Number | % | Ears segregating for both types of abnormalities % | Ears segregating for either one or both types of abnormalities % |
|---|---|---|---|---|---|---|---|---|
| Reid | 1 | 95 | 1 | 1.1 | 5 | 5.1 | — | 6.3 |
| Yellow | 2 | 428 | 20 | 4.7 | 55 | 12.9 | 0.93 | 16.6 |
| Dent | 3 | 294 | 11 | 3.7 | 40 | 13.6 | 1.70 | 15.6 |
| Illinois | 1 | 227 | 40 | 17.6 | 55 | 24.2 | 7.49 | 34.4 |
| High Yield | 2 | 94 | 56 | 59.5 | 35 | 37.2 | 26.60 | 70.2 |
| Illinois | 1 | 150 | 4 | 2.7 | 19 | 12.7 | — | 15.3 |
| Two Ear | 2 | 59 | 11 | 18.6 | 3 | 5.1 | 1.69 | 22.0 |

Attention may be drawn to the percentages of defective seeds in classes 1 and 2 of Illinois High Yield and Illinois Two Ear. It will be recalled that ears of these varieties showing observable defective endosperm types were placed in class 2. There were 19 such ears in the case of Illinois High Yield and 6 in the case of Illinois Two Ear. Expressed as percentages of the total number of ears segregating for defective seed types in class 2 of these varieties, these figures become 20.2 and 8.5, respectively. When these percentages are subtracted from 59.5 and 18.6, respectively, we have, as remainders, 39.3 and 10.1, which, respectively, are the percentages of class 2 ears of Illinois High Yield and Illinois Two Ear segregating for germless seeds and miniature germs—defective seed types that cannot be readily observed until the ears are shelled. The percentages of such segregating ears for class 1 are 17.6 for Illinois High Yield and 2.7 for Illinois Two Ear. When these percentages are contrasted with those given

above for class 2 ears, namely, 39.3 for Illinois High Yield and 10.1 for Illinois Two Ear, the better ears on the basis of general appearance are shown to have the smaller percentage of abnormal seed types. This conclusion is in line with that indicated for Reid Yellow Dent.

Classification of ears on basis of general appearance could not, of course, be influenced by the kinds or frequency of chlorophyll abnormalities present, since there was no way of knowing which ears were heterozygous for defective seedling types. Hence, the data in Table 2 may be taken to indicate that progenies of the best selfed ears are freest from chlorophyll deficient types. The opposite conclusion is indicated by the results on the Illinois Two Ear corn. However, the numbers are small in this variety.

## DISCUSSION

In discussing the frequency of mutations affecting chlorophyll development, Demerec (1) states that,

> "it seems probable that mutations having stronger detrimental effects would be more frequent than those which were less injurious. If this is the case, then it may be expected that white seedlings, as the most detrimental type of chlorophyll mutations, would be most frequent, more so than pale green, and still more than variegated and virescent types."

These statements are well borne out in the present study as shown by the data in Table 3, in which the several types of chlorophyll abnormalities are listed in the order of their total frequencies for the three varieties. It will be noted that the first four types listed, namely, albino, pale green, Japonica, and virescent are in the identical order in which they were mentioned in the above statement by Demerec. The totals for Reid Yellow Dent and Illinois High Yield are higher than the number of chlorophyll defective types given for these

TABLE 3.—*Showing relative frequency of various types of chlorophyll abnormalities following self-fertilization of different varieties of corn.*

| Chlorophyll deficient type | Variety: Reid Yellow Dent | Variety: Illinois High Yield | Variety: Illinois Two Ear | Total | % |
|---|---|---|---|---|---|
| Albino | 25 | 36 | 1 | 62 | 26.84 |
| Pale Green | 23 | 29 | 2 | 54 | 23.38 |
| Japonica | 11 | 21 | 1 | 33 | 14.29 |
| Virescent | 24 | 4 | 4 | 32 | 13.85 |
| Yellow | 8 | 3 | 7 | 18 | 7.79 |
| Lineate | 12 | — | 6 | 18 | 7.79 |
| Fine-striped | 2 | 11 | 1 | 14 | 6.06 |
| Totals | 105 | 104 | 22 | 231 | 100.00 |

varieties in Table 1, due to duplication of some ears that segregated for more than one type of abnormality.

White seedlings have appeared with more or less frequency in the ear-row breeding plat in certain of the strains of corn produced at this station by continuous selection. The ears planted were always open-pollinated and had been produced on detasseled plants. Doctor L. H. Smith states that about 20 years ago the Illinois Low Ear strain became notorious for throwing albinos in the field and that for a number of years counts were made and recorded for each row in the breeding plat. As an example of such counts, the data in Table 4 are given, showing the frequency of albino plants in each row of the breeding plat for 1910. Similar results were recorded for the 1911 breeding plat of this strain.

TABLE 4.—*Frequency of occurrence of white seedlings in Illinois Low Ear breeding plat for 1910; rows planted from open-pollinated ears borne by detasseled plants.*

| Row No. | Albinos | | Row No. | Albinos | |
|---|---|---|---|---|---|
| | Number | % | | Number | % |
| 1 | — | — | 13 | — | 0 |
| 2 | 5 | 2.39 | 14 | 25 | 14.45 |
| 3 | 15 | 7.81 | 15 | — | 0 |
| 4 | — | 0 | 16 | — | 0 |
| 5 | 9 | 7.97 | 17 | 12 | 6.94 |
| 6 | 11 | 5.67 | 18 | — | 0 |
| 7 | 19 | 11.31 | 19 | 11 | 5.61 |
| 8 | — | 0 | 20 | — | 0 |
| 9 | — | 0 | 21 | — | 0 |
| 10 | — | 0 | 22 | — | 0 |
| 11 | 5 | 4.13 | 23 | 9 | 10.23 |
| 12 | 19 | 9.95 | 24 | 26 | 12.62 |

In the High Ear plat planted and conducted in the same manner and tracing back to the same original stock of seed, no such abnormalities appeared. Doctor Smith thinks that albino genes were carried in the first parent ears of the Low Ear strain but not in those of the High Ear strain. The selection for height of ear was started in 1903 with only four ears as foundation stock. Probably during the first year or two of the experiment, ears from plants heterozygous for albinism of the Low Ear strain happened to be selected and planted. The conditions thus favored the production of a large proportion of heterozygous plants, and these, in turn, by crossing among themselves, gave rise to the unusual number of white seedlings found.

The particular method of selection and breeding here followed is thought not to have any casual connection with the appearance of an excessive number of albino seedlings. This is indicated by the fact

that during the years when the Low Ear breeding plats were throwing so many albinos, a dozen or more similar breeding plats were being conducted in like manner, to determine the effect of selection on chemical composition, the angle at which the ear is borne at maturity, multiple-eared stalks (Illinois Two Ear) and the like. Occasionally, an albino seedling would be observed in these plats, but in nothing like the frequency observed for the Low Ear. Another bit of evidence bearing on this point is that furnished by selfed ears of the Illinois Two Ear corn described in the present study. As here shown, the percentage of chlorophyll abnormalities in this strain is no greater than in Reid Yellow Dent which has been propagated by mass selection for an indefinite period of years.

Similarly, the ear-to-row system followed in the development of Illinois High Yield corn is thought not to be responsible for the high percentage of abnormalities shown by this variety following self-fertilization. While this system differed in a few details from that followed in the development of the other Illinois corn strains mentioned above, the main principle was the same, namely, selection of seed from rows in the breeding plat giving the highest yield. The main difference was that in addition to yield, particular attention, in the case of the continuous selection strains, was paid to chemical composition, or a size character such as height of ear. There is no conceivable connection between this difference in method of production of the continuous selection strains and Illinois High Yield and the high percentage of seed and seedling abnormalities shown by the latter variety.

Finally, the varieties reported on by Hayes and Brewbaker showed as great differences in percentage of abnormalities as the strains studied in this experiment, even though presumably they had all been propagated by mass selection prior to selfing. The particular method of breeding followed in producing a strain of corn, therefore, is believed not to have any relation to the relative frequency or accumulation of factors for seed and seedling abnormalities. Probably mutations for seed and seedling abnormalities in corn occur more frequently in some varieties than in others for reasons that are at present unknown.

## SUMMARY

Studies on a large number of self-fertilized ears of Reid Yellow Dent, Illinois High Yield, and Illinois Two Ear corn brought out the following facts:

1. Percentage of seed and seedling abnormalities varied greatly for these varieties, Illinois High Yield showing about three times the percentage shown by Reid Yellow Dent and Illinois Two Ear.

2. There appears to be a slight relation between the general appearance of the ears and the percentage of seed and seedling abnormalities, the better appearing ears showing the smaller percentages.

3. Entire absence of chlorophyll (albinism) was the most frequent chlorophyll defective type found followed by pale green, Japonica, virescent, yellow, lineate, and fine striped in the order named.

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# NOTES

## A CONTAINER AND CASE FOR CARRYING ACID IN THE FIELD

It is often necessary in the field investigation of soils to test for calcareous material. Various devices for carrying acid in the field have been tried and discarded. The acid container and carrying case illustrated in Fig. 1 have been in use by the Illinois soil survey during the present season and have proved to be satisfactory. The carrying case, constructed of leather, provides a means of carrying pencils, a brass rule, and pen, if desired, as well as a safe place for the acid vial. The back of the case is constructed of light sole leather to give stiffness and the front is made of a light pliable leather. It has been found advisable to treat the case with a waterproof dressing to protect it from perspiration. A 13-gauge spring steel wire placed in the pencil compartment of the case, as illustrated, gives sufficient tension to hold the pencils with no danger of their loss.

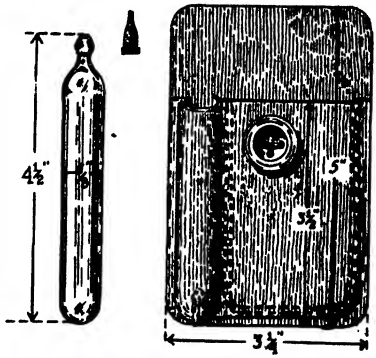

FIG. 1

The acid vial is constructed of pyrex glass, thus practically eliminating danger of breakage. The diameter of the vial is not a matter of importance; an external diameter of 16 mm has proved to be very convenient. It is important to have the opening close to 1½ mm in diameter. An opening of this size delivers the proper sized drops and is large enough for filling by means of a medicine dropper, the point of which has been drawn out. The vial contains enough acid for a large number of carbonate tests, about 200 large drops. Some tests require more than one drop, but rarely is it necessary to use more than three or four to be sure effervescence does or does not occur. The experience of nine men during the present field season shows that a vial full of acid is adequate for a day's work even though tests are constantly being made.

The vial is closed by means of a rubber "policeman," or better, by a cap made of high-grade rubber tubing cemented shut at one end and the other end turned back and cemented, thus eliminating any tendency for the tube to work off the vial. The case should be placed in the shirt pocket so that the upper edge of the pliable leather is above the cloth of the pocket, thus avoiding any interference with inserting acid vial and pencils in the case.

The advantages of this device for carrying acid in the field are that the drops of acid can be placed on the exact spot desired, danger to clothes from spilling is eliminated, the acid does not run on the outside of the vial, and an adequate supply is always immediately at hand.—R. S. SMITH, *Department of Agronomy, University of Illinois, Urbana, Ill.*

## AN EFFECTIVE BARRIER FOR CONTROLLING THE MIGRATION OF CHINCH BUGS

Chinch bugs are frequently a serious pest in many parts of the corn belt and the Great Plains region, particularly in connection with experimental plats where wheat and other small grains are grown adjacent to plats of corn or grain sorghums. Several methods have been proposed for checking the movement of these insects from infested fields of small grain to other areas of land. However, the most commonly used method at the present time is some form of the barrier system.[1]

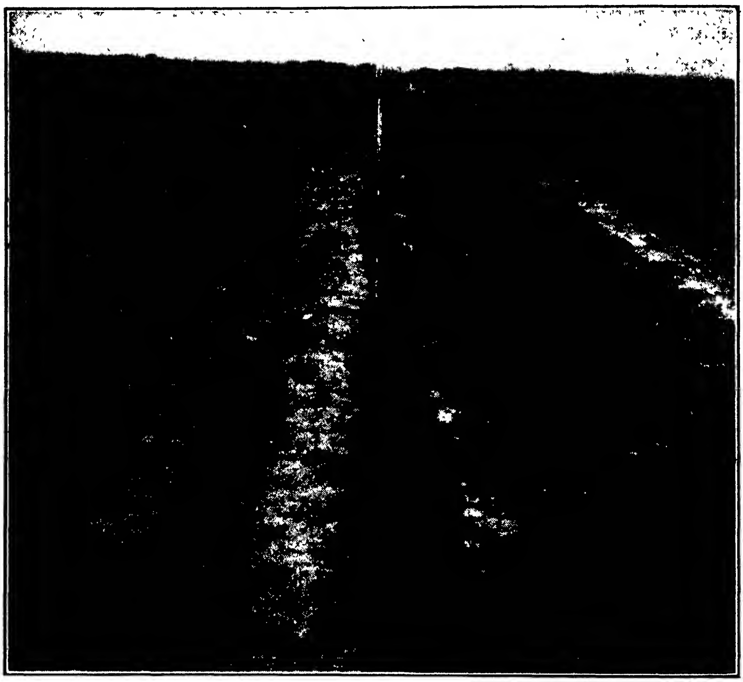

FIG. 1.—Trench with cottonseed and oil barrier for controlling migration of chinch bugs.

Conditions seem to be favorable for the development of chinch bugs at the Oklahoma Agricultural Experiment Station, and for a long period of time they have been annual visitors. During the past season they were more abundant than usual. Practically all of the methods for chinch bug control which have been suggested by various

[1]FLINT, W. P., and LARRIMER, W. H. The chinch bug and how to fight it. U. S. D. A. Farmers' Bulletin 1498. 1926.
McCOLLOCH, J. W. Chinch bug barriers for Kansas conditions. Kan. Agr. Exp. Sta. Circ. 113. 1925.
SWENK, M. H. The chinch bug and its control. Nebr. Agr. Exp. Sta. Circ. 28. 1925.

investigators have been used at various times on the experimental plats. However, as a result of necessity a method was devised this past year (Fig. 1) which is superior to other methods previously used because it is inexpensive and because the materials are always readily available and can be secured in large quantities.

The method used was as follows: A small trench about 3 inches wide and 2 inches deep was dug around the area to be protected or around the infested area, whichever required the least amount of trench. Either a hoe or a small pointed shovel on a cultivator can be used to make the trench. The trench was moistened with water and then filled with cotton seed which had plenty of lint left on it. About 100 pounds of seed will fill 500 feet of trench. Waste cylinder oil which can be secured from filling stations and garages was applied to the cotton seed until it was thoroughly saturated. An application of oil about 3:00 o'clock each afternoon was sufficient to keep the seed moist and keep the barrier effective. Holes were dug as recommended for the tar and creosote barriers to catch the chinch bugs which followed along the barrier. Also, frequent applications of calcium cyanide dust were made to kill the insects where they had accumulated in large numbers on the surface of the ground along the barrier. The trench should not be made too deep because bugs falling into it gradually accumulate and may form a bridge on which the live insects can cross into the uninfested area. It is preferable to have the vegetation cleared away from the area near the trench as recommended by other investigators. Rain does not harm the oil barrier unless soil is washed onto it from the surrounding area.

The advantages of the cotton seed or some other absorbent material as compared with a trench alone is that the oil will not be absorbed by the soil and remains effective for a much longer period of time. Also, the excess oil will not run along the trench and accumulate in low places.

Cotton seed is inexpensive in regions where it is available and in other areas it could be shipped in, or some other absorbent material could be substituted for it.—HORACE J. HARPER AND CLYDE D. HASTON, *Oklahoma Agricultural Experiment Station, Stillwater, Oklahoma.*

# AGRONOMIC AFFAIRS

## ANNUAL MEETING OF SOCIETY

Although details of the program are lacking, the general plan for the annual meeting of the Society has been announced by Secretary Brown as follows. The sessions will be held in the Hotel Stevens, Chicago, November 14 and 15. The first morning will be devoted to a general session when several papers of agronomic interest will be presented by well-known speakers. On the afternoon of the 14th, the Soils and Crops Sections of the Society will hold separate sessions with a symposium on phosphorus led by Dr. F. C. Bauer of the University of Illinois in the Soils Section and a symposium on alfalfa led by Professor R. I. Throckmorton of the Kansas State Agricultural

College in the Crops Section. The dinner and business meeting will be held on the evening of the 14th, and will be featured by the address of the retiring President.

On the morning of the 15th, the program of the Soils Section will deal with peat investigations and one or two other items of special interest to soil specialists. The Crops Section will have papers on weed control, field plat methods, and other subjects. The afternoon session will be given over to the presentation of contributed papers before the Society as a whole.

All members of the Society attending the meeting are urged to buy a one-way ticket to Chicago, securing a certificate from their ticket agent. If a sufficient number of these certificates are validated at the meeting, the return trip can be made for half fare. This applies to members of the Society and their families.

## MEETING OF NEW ENGLAND SECTION

The annual meeting of the New England Section of the Society will be held in the Hotel Kimball, Springfield, Mass., November 29 and 30, according to a preliminary announcement made by M. H. Cubbon, Secretary of the Section. There will be formal sessions on the afternoon of the 29th and in connection with the banquet that evening and on the morning of the 30th. It is expected that the program will be announced in the November issue of the JOURNAL.

## MINUTES OF 1929 MEETING OF WESTERN SECTION

The thirteenth annual conference of the Western Section of the American Society of Agronomy was held at Pullman, Washington, and at Moscow, Idaho, from July 15 to 17. The attendance by states was as follows: Washington, 19; Idaho, 17; Oregon, 8; California, 4; Montana, 3; Utah, 2; North Dakota, 1; Wyoming, 1; and the U. S. D. A., 4.

### PROGRAM

PULLMAN, WASH., JULY 15

Roll Call—answered by a self-introduction and brief resumé of problems under investigation.

Address of Welcome, Dr. E. O. Holland, President, State College of Washington.

Response, D. E. Stephens, Sherman County Branch Exp. Sta., Moro, Oregon.

The yield and Chemical Composition of Oats and Clover as influenced by Fertilizer Treatments on Western Washington Soils, R. E. Bell, State College of Washington.

Comparative Yields of Carbohydrate and Nitrogenous Material in Wheat as Effected by Different Nitrogen Relationships, Lloyd D. Doneen, State College of Washington.

The Rôle of Sulfur in Plant Nutrition, E. F. Torgerson, Oregon State College.

The Place of Nitrogen in Organic Matter Maintenance, H. F. Holtz, State College of Washington.

Comparative Differences in the Potassium, Phosphorus, and Nitrogen Content of Apple Leaves and Twigs as Results of Fertilizer Treatments, Carl A. Larson, State College of Washington.

Soil Fertility as Related to Irrigation Requirements, W. L. Powers, Oregon State College. Presented by E. F. Torgerson.

The Functions of Certain Groups of Micro-organisms in the Process of Organic Matter Decomposition in the Soil, S. C. Vandecaveye, State College of Washington.

Inheritance Studies in a Cross Between Federation and a Segregate of Dicklow by Sevier, Geo. Stewart, Utah Experiment Station.

Solving Field Problems in Agronomy, Leonard Hegnauer, State College of Washington.

Root Cutting Experiments in Connection with Grain Sorghum Harvesting, John P. Conrad and E. J. Stirniman, University of California. Presented by J. P. Conrad.

Correlation Between the Quantitative Characters in Hard Red Winter Wheat, L. L. Davis, Aberdeen (Idaho) Experiment Station.

Discussion of Methods and Technic of Agronomic Experimentation, led by H. W. Hulbert, Idaho Experiment Station.

### Pullman, Wash., July 16

Symposium on "Bunt or Stinking Smut"

1. Experiments with Bunt in Spring Wheat in North Dakota, Ralph W. Smith, U. S. D. A.

2. Inheritance of Resistant Varieties to Bunt, F. N. Briggs, University of California.

3. Physiologic Forms of Bunt, E. N. Bressman, Oregon State College.

4. Inheritance of Resistance to Physiologic Forms of Bunt, W. K. Smith, State College of Washington.

5. Discussion, led by D. E. Stephens, Moro, Oregon.

### Moscow, Idaho, July 17

Symposium on "Weed Control"

1. Investigation with Chlorater for Weed Control in Idaho, H. W. Hulbert and J. D. Remsberg, Idaho Experiment Station.

2. Eradication of Weeds by Chemical Sprays, O. E. Lee, State College of Washington.

3. Discussion, led by E. G. Schafer, Washington Experiment Station.

Symposium on "Pasture Experiments"

1. Management of Irrigated Pastures, F. W. Atkeson, Idaho Experiment Station.

2. Seeding Grasses in Burns on Cut-Over Lands, J. H. Christ, Sandpoint (Idaho) Experiment Station.

3. Discussion of Forage Problems, led by A. J. Pieters, U. S. D. A.

The afternoon of the 16th was spent in visiting the cereal nurseries and agronomic experiments at the Washington and Idaho Experiment Stations. The annual banquet was held at the Moscow Hotel Tuesday evening, July 16. The address of welcome was delivered by E. J. Iddings, Director of the Idaho Experiment Station, with a response by Dr. E. F. Gaines, of Washington State College, President of the Western Section of the Society. Members of the Idaho Station

staff furnished transportation to Sandpoint, Idaho, for those interested in visiting the branch station located there. At this station very interesting results are being obtained in seeding grasses on the cut-over and burned forest land.

An invitation extended the conference by Clyde McKee to meet in Montana in 1930 was accepted. George Stewart, Agronomist at the Utah Experiment Station, Logan, Utah, was elected President; and B. B. Bayles, Assistant Agronomist, U. S. D. A., Moccasin, Montana, Secretary.—B. B. BAYLES, *Secretary.*

## NEWS ITEMS

B. J. FIRKINS, Associate Professor of Soils at Iowa State College, appeared on the Chautauqua program at Washington, Iowa, August 19, when he lectured on "Soils and Soil Problems."

ARTHUR W. YOUNG, of Iowa State College, and Dean A. Anderson, of Brigham Young University, have been appointed to fellowships at Iowa State College where they will take up graduate work in soils for the ensuing year.

E. B. EARLEY, for the past year Fellow in Agronomy at the Virginia Polytechnic Institute, has been appointed full-time assistant in soils in the Illinois Agricultural Experiment Station, effective September 1.

T. W. WEBB, a 1929 graduate of Clemson College, has been appointed Fellow in Agronomy in the Virginia Polytechnic Institute, Blacksburg, Virginia, effective September 1.

W. H. METZER, Assistant Agronomist at the Arkansas Agricultural Experiment Station, has accepted a two-year fellowship at Ohio State University offered by one of the largest lime producers in Ohio. Work under the fellowship will provide an opportunity for completing requirements for the Ph. D. degree.

SCIENCE records the death on July 20 of Dr. Peter A. Yoder, Chemist and Sugar-cane Technologist in the Bureau of Plant Industry, U. S. Dept. of Agriculture.

J. D. WARNER, Assistant Agronomist, South Carolina Experiment Station, resigned September 30 to accept employment with the Florida Experiment Station with headquarters at Gainesville.

THE following have been appointed to assistantships on the Agronomy staff at the University of Illinois: E. B. Earley, Soil Analysis; C. H. Farnham, Soil Experiment Fields; Allan Kirkwood, Soil Experiment Fields; W. D. Gifford, Soil Biology; M. L. Harshberger, Soil Biology; and C. A. VanDoren, Crop Production.

A. L. LANG, Associate in Soil Experiment Fields, has returned to the University of Illinois after a year's graduate study at Cornell University.

JOHN LAMB, JR., Associate in Soil Experiment Fields, University of Illinois, has been appointed to an assistantship on the soils staff at Cornell University.

R. W. STARK, University of Illinois, has retired after many years of service as Associate in Crop Production, to look after personal interests. Mr. Stark has devoted particular attention in recent years to the improvement of wheat.

H. F. A. NORTH has been appointed Assistant Agronomist at the Rhode Island Agricultural Experiment Station, effective November 1. Mr. North will take the position vacated by E. S. Garner who has resigned to accept a position with the English Government in Palestine.

JOURNAL

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# SYMPOSIUM ON "APPLICATION OF BASE EXCHANGE METHODS"

## 1. THE DETERMINATION OF THE BASE-EXCHANGE CAPACITY OF SOILS AND A BRIEF DISCUSSION OF THE UNDERLYING PRINCIPLES[1]

W. P. KELLEY[2]

The determination of the replaceable ions of a soil involves the necessity for giving special consideration to two factors, namely, solubility as contrasted with ion exchange and the differential energy of adsorption, as it is sometimes called, of the different ions.

As is well known, soils commonly contain one or more components that are soluble to some extent in ordinary salt solutions. Various compounds may be involved. Some of these are readily soluble in water and can be removed by leaching with water. Others are only slightly soluble in water, yet decidedly soluble in certain salt solutions. Prominent among such compounds is $CaCO_3$. As is well known, $CaCO_3$ is markedly soluble in neutral solutions of the ammonium salts and distinctly soluble in neutral salts of the alkalies. The solubility of various other substances that occur in soils is also too great to be entirely ignored. It is true the more soluble constituents of relatively mature soils, especially if they do not contain carbonate, have probably been largely leached out in the state of nature, or else they have been converted into less soluble and more stable constituents. Yet it is questionable whether solubility can be entirely disregarded in the accurate determination of the exchange bases of any soil.

The solubility factor is especially important in connection with the soils of dry climates. For example, every soil that we have studied from the western states yields a quantity of bases upon extraction with NaCl, KCl, or $NH_4Cl$ in excess of the Na, K, or $NH_4$ that is absorbed from the solution. This difference must be attributed to solubility.

[1]Paper read as part of the symposium on "Application of Base Exchange Methods" at the meeting of the Society held in Washington, D. C., November 22, 1928.

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In this connection, it should be remembered that the solubility factor may itself be a relatively complex process in that it may involve more or less hydrolysis with the consequent transformation of the original compounds into different chemical individuals. In fact, the solution of the natural silicates in general is not as simple a process as is that of sodium chloride or other simple salts. This is proved by the fact that the ratios of the elements comprising the solubility product of the silicates ordinarily differ materially from the ratios of the total quantity of these elements in the silicates themselves.

The differential energy of absorption of different ions is also well established. This means that certain ions are more difficult to replace than others. Reference is made here not to the fact that the base of certain compounds is more difficult to replace than the base of totally different compounds, but rather that when the exchange complex contains certain ions in replaceable form, these ions may be more easily replaced than is the case when certain other ions are held by the exchange complex. Gedroiz called attention to this fact several years ago. For example, Na is rather easily replaced by Ca, whereas Ca is by no means so easily replaced by Na. In fact it is extremely difficult to effect the complete replacement of the last traces of replaceable Ca by means of Na.

It is not my purpose to discuss the reasons which underlie the differential energies of absorption of different ions. Such a discussion would lead at once into speculative questions involving the mechanism of ion exchange, ion hydration, electronic structure of atoms, the micell theory of the colloidal particle, etc. Suffice it to say that certain ions are held much more tenaciously by soils and are therefore more difficult to replace than others.

It is in this connection that the H ion becomes especially important and that special difficulties arise in the determination of the base-exchange capacity. The fact that the bases may be replaced by H ions is of course well known. Moreover, it is clearly established that H ions, formed in soils by biochemical action or introduced by carbonated water, may have replaced more or less of the replaceable bases. Acid soils represent essentially this very condition wherein the H ion has replaced base from the exchange complex with the resulting formation of acidic compounds. Obviously, the replaceable base content of a given soil has been diminished by whatever amount the H ion has replaced the bases. Therefore, the determination of the base-exchange capacity of an acid soil necessitates giving consideration to the hydrogen ion as well as to the bases.

The method which we use for the determination of the base-exchange capacity has been developed with a view to securing an accurate measure of the total quantity of replaceable ions, whatever their nature. The method as such does not determine just what ions the soil contains in replaceable form. It is designed merely to give a measure of the total quantity of replaceable ions present.

The method embraces three points: First, the saturation of the soil with base, that is the replacement of H ions by base; second, the

complete displacement of the replaceable bases by a base which does not occur to any important extent in the natural soil, and which at the same time does not form insoluble compounds with constituents of the soil other than the exchange complex; third, the determination of the quantity of that base which the soil has thus absorbed in consequence of the replacement of its bases.

The details of the method are essentially as follows: The air-dried soil is first passed through a 40-mesh sieve and its pH is determined. Unless it is definitely alkaline, a sample of the soil, usually 10 grams, is given a preliminary treatment with $Ba(OH)_2$ in order to replace its H ions by barium. Where this preliminary treatment is found necessary the analytical sample is digested with 100 cc of N/10 $Ba(OH)_2$ for a period of 24 hours. After filtration the sample is transferred to a flask without making any attempt to remove the excess of $Ba(OH)_2$. If the soil is definitely alkaline, the preliminary digestion with $Ba(OH)_2$ is dispensed with. Approximately 100 cc of neutral normal $NH_4C_2H_3O_2$ is added to the flask. After vigorous shaking the flask is held over night in an oven kept at approximately 70°C. The next morning the entire contents of the flask is quantitively transferred to a filter paper and the soil is leached with fresh portions of the $NH_4C_2H_3O_2$ solution as long as the leachate gives a test for divalent base. Unless the soil contains considerable $CaCO_3$, 400 cc of the acetate solution will usually suffice. The soil residue is then leached with pure methyl alcohol in order to remove the occluded acetate. When the $NH_4C_2H_3O_2$ has been completely removed, as indicated by the Nessler test, the soil, together with the filter paper, is transferred to an 800-cc Kjeldahl flask and approximately 200 cc of 5% $(Na)_2CO_3$ are added. The $NH_4$ is then determined by aeration. We find it necessary to continue the aeration for at least 12 hours. Ordinarily the aeration is carried out at night with six or more samples connected in series, an ordinary water pump being used to provide suction.

As used by us at the present time, the method embodies a few modifications of our former technic. The more important of these is that methyl alcohol instead of water is used to leach out the occluded $NH_4$ salt. Several investigators have found that the $NH_4$-saturated exchange complex undergoes slight hydrolysis when leached with water. This does not take place to any important extent with methyl alcohol. More important is the fact, however, as was pointed out by Hissink, that the colloidal material of the $NH_4$-saturated soil becomes highly dispersed when brought into contact with water, with the consequent tendency for the fine particles to pass through the filter when it is leached with water. Alcohol, on the other hand, coagulates the colloidal material and thus reduces this error to a low minimum.

The second modification consists in the determination of the absorbed $NH_4$ by the aeration process in the presence of $(Na)_2CO_3$ rather than by distillation in the presence of a strong alkali. This modification was found necessary because of the fact that certain organic nitrogen compounds of the soil tend to undergo more or less decomposition into $NH_3$ when distilled with a strong alkali.

Recently, we have adopted the use of $NH_4C_2H_3O_2$ in place of $NH_4Cl$. The advantages of $NH_4C_2H_3O_2$ over $NH_4Cl$ have been well stated by Scholenberger who proposed the use of this salt. Our data indicate that approximately the same amount of $NH_4$ is absorbed from $NH_4Cl$ as from $NH_4C_2H_3O_2$, provided that the soil has been previously treated in such way as completely to replace H ions by base. On the other hand, if the soil contains replaceable H ions, a greater quantity of $NH_4$ will be absorbed from $NH_4C_2H_3O_2$ than from $NH_4Cl$. This is probably due to the fact that $NH_4C_2H_3O_2$, being a salt of a weak acid, is more effective in the replacement of H ions than is $NH_4Cl$, a salt of a strong acid. In fact, various workers have shown that a greater amount of H ions can be replaced by acetates than by chlorides[3]. Our data indicate that the H ions can be practically completely replaced from the inorganic exchange complex by direct extraction with $NH_4C_2H_3O_2$ without the preliminary treatment with a strong alkali. When $NH_4Cl$ is used in studies on base exchange, it has been our practice for some time to adjust the pH to 7. Not infrequently this reagent, as it comes on the market, is distinctly acid. Moreover, $NH_4Cl$ is an acid salt and its solution is normally acidic.

Other details, together with considerable experimental data obtained in working out this method, will be discussed in the near future in a separate paper by Dr. Chapman.

A little reflection will show that to whatever extent solubility may be involved upon treating a soil with $NH_4C_2H_3O_2$, the products of this solubility do not in any way complicate the results as obtained by this method, in so far as the determination of the exchange capacity is concerned. The dissolved products, as well as the replaced bases, are leached away and rejected. The most important assumption in connection with this method relates to the stoichiometry of ion exchange. It is assumed that for every equivalent of $NH_4$ that is absorbed by the soil, a chemical equivalent of some other ion has been replaced, and conversely that for every ion which has been replaced a chemical equivalent of $NH_4$ has been absorbed by the soil. Obviously, any base that is merely dissolved, even though its solution may involve hydrolysis, is not accompanied by the absorption of $NH_4$.

The method recommended by Hissink (1)[4] for the determination of the exchange capacity consists, first, in the determination of the replaceable bases and, second, in the determination of the amount of $Ba(OH)_2$ that the soil is able to absorb. The sum of these two quantities, expressed as chemical equivalents, Hissink considers to be a true measure of the exchange capacity of the soil. We believe that

[3]With certain types of acid soils treatment with $NH_4Cl$ brings about the replacement of more or less H ions by $NH_4$. Consequently, the $NH_4$ absorbed from $NH_4Cl$ is, as Parker has pointed out, not a true measure of the total replaceable-base content (S) of such soils; hence the increased amount of $NH_4$ that the soil is capable of absorbing as a result of treatment with $Ba(OH)_2$ is not a true measure of the replaceable H-ion content of the soil, as was assumed to be the case in a previous paper (Kelley, W. P., and Brown, S. M. Base unsaturation in soils. Proc. 1st Internat. Cong. Soil Sci., 2:491–507. 1927.)

[4]Reference by number is to "Literature Cited," p. 1029.

this method is inaccurate for two reasons: First, the method which Hissink uses for the determination of the replaceable bases makes inadequate provision for solubility and with certain soils it does not even effect the complete replacement of the soil bases; and second, and much more important, the amount of $Ba(OH)_2$ which a soil is capable of absorbing is by no means an accurate measure of the replaceable H ions of the exchange complex.

Various substances common to soils, such as colloidal $SiO_2$, $Al_2O_3$, $Fe_2O_3$, and many different silicates, have the power to absorb notable amounts of $Ba(OH)_2$. The amount which is absorbed is dependent in part at least on the OH-ion concentration of the solution. In a recent paper, Hissink (2) stated that all of the Ba that is absorbed upon treating the soil with $Ba(OH)_2$ is held in replaceable form, but he gives no data in support of this statement. I take it that he means that all of the absorbed Ba is extracted upon leaching with a solution of NaCl or $NH_4Cl$. If so, it need only be pointed out that such evidence does not constitute adequate proof of replaceability.

Although it must be admitted that much remains to be determined regarding the base-exchange compounds of soils, it is possible that in a certain sense the complete saturation of these compounds with base may require treatment with a strongly alkaline solution. This might result from the fact that these compounds are salts of very weak acids, as Page has suggested, and, therefore, they hydrolize readily. On the other hand, these compounds may absorb base from strong alkalies through the substitution of the hydrogen of their water of hydration, or by the replacement of water of hydration, or by virtue of secondary valence.

In any case, it is not the base that a soil is able to absorb from strongly alkaline solution that gives to the soil its agriculturally important properties. Rather it is the base that is actually replaceable by the base of a neutral salt solution, and that, too, which can take place within a limited range of H-ion concentration. The replaceable bases can be replaced by any one of various bases and also by H ions. The significant replaceable base content is, therefore, that quantity of base which the soil can hold within a range of H-ion concentration that prevails in natural soils.

Because of its fundamental importance in connection with methods for the study of base exchange, it seems desirable to consider briefly certain theoretical aspects of this question. It seems especially important that we come to an understanding on the question, Just what is the base-exchange complex of soils and what do we mean by the term "base exchange?"

There is sufficient evidence to justify the positive statement, it seems to me, that, with the possible exception of special instances, the inorganic-exchange complex resides largely in the clay material of the soil. It is the colloidal material, therefore, that is the chief seat of the exchangeable ions. This means that the inorganic exchange substance or substances are altered products and not the primary minerals out of which the soil has been formed. The clay materials undoubtedly represent the products of weathering and are

composed for the most part of alteration products formed by meteoric waters acting upon the primary minerals out of which the soil has been formed. Clays, therefore, whether they occur in soil or elsewhere, are not finely pulverized but otherwise unaltered primary minerals. When we speak of the base-exchange complex we do not refer to the feldspars or other similar minerals.

It is true, as has been shown by Lemberg, Sullivan, and others, that various primary silicates can be caused to undergo ion exchange to some extent by suitable treatment. But this exchange is not that which gives special interest to this subject in an agricultural sense. Moreover, so far as has been determined, no amount of grinding of granite, for example, will give to it an exchange property at all comparable to that of the clay which is formed by the weathering of granite.

It must be admitted, of course, as was shown previously by myself and others, that upon treating a soil with a salt solution a small part of the bases of the primary minerals undergo replacement. This is one of the various complications that arise in the study of this question. However, the amount of base that is derived from such minerals is not of very great magnitude.

I consider it to be safe to say that the inorganic exchange constituents of soil are not zeolites. They are clays in contradistinction to zeolites, as Clarence S. Ross of the U. S. Geological Survey has recently pointed out.[5] In my opinion, the base-exchange constituents of soils are not identical with, nor fundamentally similar to, such synthetic substance as permutite and similar preparations. All of the synthetic products thus far described differ from the base-exchange constituents of soils so widely as to necessitate the greatest caution in drawing conclusions with respect to the one from studies on the other.

One of the important particulars wherein the inorganic base-exchange constituents of soils differ from the synthetic products is in connection with stability. The soil material is relatively stable; indeed were it not for this fact the exchange material would not exist in old soils. The synthetic products, on the other hand, are relatively unstable. It is possible to replace practically all of the replaceable base from the soil by H, either by treating the soil with an acid or a salt of a trivalent base, or by electro-dialysis, without effecting any appreciable decomposition of the exchange complex.

Although it is, of course, well known that the base-exchange compounds can be decomposed by suitable treatment, and although it is possible that these constituents undergo gradual decomposition as the soil becomes increasingly unsaturated with respect to base, nevertheless, the base-exchange capacity of a soil is probably as nearly a fixed quantity as is that of any other of its constituents. Within the range of H-ion concentration that prevails in ordinary soils, that is between pH 5 and pH 8, the base-exchange constituents are remarkably stable. Within this range of H-ion concentration

[5]Personal communication.

they undergo little change save that of translocation into different horizons of the soil profile and the replacement of one ion by another.

For some time it has been held that the exchange material of soils is of two kinds, namely, inorganic and organic. Several workers have hypothecated that the former is essentially a salt of some complex alumino silicic acid. Although it would be premature to make a positive statement, there seems to be some evidence that the exchange material is made up of one or more compounds, only a portion of the base of which is replaceable. It is possible that the nonreplaceable base accounts, in part at least, for the stability of the molecule.

It seems reasonable to assume that the replaceability or nonreplaceability of the base depends upon its position in the molecule. Although the molecular structure of the silicates is a complex and difficult question and its understanding is far from complete, it appeals to me as being reasonable to assume that the position of the base in the silicate molecule and the nature of the linkage therein determine whether or not it can be easily replaced. The analogy to certain organic substances of known structure at once suggests itself. We know, for example, that the H in the alpha position of the benzine ring is much more easily substituted by the halogens than the other H's of this compound and that certain H atoms of various other organic molecules are much more easily replaced than others. Similarly, the first and second H's of phosphoric acid are much more easily replaced by base than the third H.

It seems logical to assume, therefore, that the molecules of the alteration products that are involved in the exchange of ions in soils contain bases in different positions, some of which are readily replaced and others not so easily replaced. The results obtained by electro dialysis experiments indicate that the exchange material ionizes; the cation being the replaceable base or the H ion, and the anion being the complex particle which migrates toward the positive pole and which contains $SiO_2$, $Al_2O_3$, and the nonreplaceable bases.

Gedroiz pointed out several years ago that the replaceable Ca of soils which contain no $CaCO_3$ comprises the major part of the Ca which is soluble in dilute HCl, whereas only a small part of the acid-soluble K and Mg are replaceable. In our studies on the colloidal material separated from certain soils, we have also found that the greater part of its Ca is replaceable, but that only a small fraction of the Mg and K is repleaceable. In studies now being conducted on certain natural substances separated from the clay-like material known as bentonite, Vanselow has found that only a part of the Mg is replaceable. Thomas has called attention to similar results obtained with a clay from Utah.

Ross and Shannon (3) have shown that the dominant mineral of the widely distributed natural clay known as bentonite is montmorillonite. This mineral is a magnesium aluminum silicate, a part but not all of the magnesium of which is replaceable. Recently, Ross, Shannon, and Gonyer (4) have shown that the magnesium mineral known as vermiculite also undergoes base replacement comparatively readily.

The fact that the properties of the bentonitic clays are remarkably similar to those of the inorganic colloidal material of soils, that the base-exchange property of bentonite is probably mainly due to its montmorillonite, and that with each of these materials the predominant nonreplaceable base is Mg, suggests that the inorganic-exchange complex of soils is composed, in part at least, of Mg compounds. With both the soil and the bentonitic clays, the base or bases, which are actually present in replaceable form, depend on the composition and concentration of the solutions with which they have been in contact. In the case of soil, Ca is the dominant replaceable base that occurs in humid regions, whereas Na is more prominent in arid regions. On the other hand, Mg constitutes a large part of the replaceable base of soils derived directly from highly magnesian minerals, such as occur in certain parts of California and the Hawaiian Islands.

It seems desirable to point out in this connection that it does not necessarily follow that the inorganic exchange material of soils is always composed of a single chemical compound, or the same proportion of a group of different compounds. This question has recently been discussed by Kerr (5) and has been under special investigation by our laboratory for some time. It seems probable, however, that the exchange material of a given soil is composed of closely related compounds, perhaps an isomorphous series having similar properties. Nothing seems to be gained by calling these constituents adsorption compounds. We believe that they are true chemical compounds.

As is well known, various workers hold that organic substances may be involved in the base-exchange reaction of soils. From our investigations we have become quite convinced that organic substances are actually involved in the exchange of bases of natural soils. We are unable to see any reason whatever why the exchange, which manifestly takes place in the organic constituents upon treatment with a salt solution, is not as truly a chemical process as is the case with the inorganic constituents.

As I have already suggested, the materials referred to as the exchange complex are not necessarily the only constituents of soils that are capable of reacting with salt solutions. It is, of course, well known that $CaCO_3$ can be converted into $BaCO_3$ and $CaCl_2$ by leaching with a solution of $BaCl_2$. In a similar way calcium metasilicate can be converted into insoluble barium silicate by leaching with $BaCl_2$. Conversions of this kind obviously involve an exchange of bases. Since various substances representing intermediate products of weathering occur in the soils of the semiarid region, and since $BaCl_2$ will react with such substances with the formation of insoluble Ba compounds, the $BaCl_2$ method for the determination of the replaceable bases is objectionable. This method, however, is probably reasonably accurate with acid soils.

From the foregoing discussion it must be apparent that to apply the term "base exchange" to every reaction wherein the base of a solid becomes substituted by the base of a solution is to rob it of precision. Such usage makes the term essentially synonymous with the

term metathesis. As I see the matter, it is a rather restricted class of substances whose base is replaceable that imparts to soils those peculiar and important properties which give to the base-exchange phenomenon its special agricultural significance. These are the relatively stable products of weathering and the inorganic substances are probably alumino silicates.

In the light of these ideas I am of the opinion that soil investigators are justified in rather arbitrarily restricting the use of the term "base exchange." Instead of applying the term to all bases that can be extracted by means of any salt solution, we have concluded, for the present at least, to apply the term "replaceable base" to those bases which can be readily replaced by a neutral salt solution of a monovalent base. The term "base-exchange capacity" we use to denote the maximum quantity of base that the soil is capable of absorbing from a neutral solution of a monovalent base.

It must be obvious from the foregoing discussion that the proposed restriction in the use of the term "replaceable base" does not imply that the bases in question can not be replaced by divalent base. As a matter of fact the divalent bases are more active replacing agents than the monovalent bases. Rather it is offered for the reason that the salts of certain divalent bases, Ba for instance, are capable of reacting with substances other than the exchange complex which occurs in certain soils, with the consequent bringing of bases into solution from such substances, and the simultaneous absorption of divalent bases from the solution. Where Ba is used to replace the bases, there seems to be no accurate method of distinguishing between the exchange complex and these substances.

It is also important to bear in mind that the neutral salts of the monovalent bases are active solvents for certain substances which occur in greater or lesser amounts in immature soils. The result is an important error may arise in the determination of the replaceable bases owing to solubility. However, this does not interfere with the determination of the exchange capacity, since this is dependent not upon the amount of base that is extracted from the soil, but on the amount of base that is absorbed from the salt solution.

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## 2. THE ORIGIN, NATURE, AND ISOLATION OF THE INORGANIC BASE EXCHANGE COMPOUND OF SOIL

Emil Truog

This paper was presented at the symposium but was not available for publication.—Editor's Note.

## 3. THE DETERMINATION OF EXCHANGEABLE HYDROGEN IN SOILS[1]

F. W. Parker[2]

A satisfactory method or methods for the determination of exchangeable H is very necessary in many studies of soil acidity and related problems. Nevertheless, there is at present no wholly satisfactory and generally accepted method for the determination of exchangeable H. This situation may be attributed to several reasons among which may be mentioned the difficulty of replacing H by leaching with a neutral chloride, the failure to distinguish between exchangeable and non-exchangeable H, and the uncertainty as to whether or not trivalent bases are present in the exchangeable form. If the H in the exchange complex could be as readily and completely replaced by Ba of $BaCl_2$ as is the exchangeable Ca, the determination of exchangeable H would be relatively simple. When an acid soil is leached with neutral $BaCl_2$, some H is replaced and some Fe and Al come into solution. The net result has been that we have not been sure how much exchangeable H remains in the soil nor what percentage of the titratable acidity is due to the exchangeable H.

The present study was made in an effort to develop one or more methods for the accurate determination of the amount of exchangeable H in soils. This paper presents the results obtained by several methods, most of which are based on what appear to be sound theoretical considerations. In presenting these results no attempt has been made to give a comprehensive review of the literature bearing on the subject.

### THE DIFFERENCE METHOD

Studies on base exchange in soils have resulted in rather definite and generally accepted conclusions regarding several important points. Among the most fundamental conclusions reached by various investigators are three which have a definite bearing on our present problem. These conclusions may be stated as follows:

1. An acid soil contains H in the exchange complex.
2. A soil has a definite exchange capacity.
3. The exchange reaction is one of chemically equivalent exchange.

[1]Paper read as a part of the symposium on "Application of Base Exchange Methods" at the meeting of the Society held in Washington, D. C., November 22, 1928. Contribution from the Soils Laboratory, Department of Agronomy, Alabama Agricultural Experiment Station, Auburn, Ala. Published with the approval of the Director.

[2]Soil Chemist.

The first conclusion is generally accepted. It does not state that soils having a pH value above 7.0 do not have H in the exchange complex. Neither does it eliminate the possibility of the presence of exchangeable Fe and Al. The second conclusion simply states that soils have a definite exchange capacity. It does not imply that the exchange capacity cannot be altered, but it does indicate a definite measurable capacity rather than an indefinite indeterminate capacity. According to the third conclusion, the exchange reaction proceeds in accordance with the stoichemetric laws of chemistry. When Ba replaces H or Ca, the amount of Ba entering the exchange complex is chemically equivalent to the H and Ca replaced.

The importance of these three fundamental conclusions becomes very evident when we consider the determination of exchangeable H in soils. In an acid soil, the exchange capacity of the soil is satisfied by bases and H, or by H alone if the soil is completely desaturated. The sum of the exchangeable bases and exchangeable H should be equivalent to the exchange capacity of a soil. Conversely, the difference between the exchange capacity of a soil and its content of exchangeable bases should be equivalent to the exchangeable H content of the soil. Such a method for the determination of exchangeable H may be called "the difference method."

The difference method is fundamentally sound if the conclusions mentioned above are correct. To be accurate, however, the method requires an accurate determination of the exchange capacity and of the sum of the exchangeable bases in a soil. Hissink (1)[3] used the difference method for the determination of exchangeable H and the calculation of percentage saturation (V). Kelley and Brown (4)[4], however, have shown that Hissink's results are incorrect due to a fundamental error in the determination of the exchange capacity of the soil. Kelley (2) suggested that the exchange capacity of a soil is equivalent to its absorptive capacity for $NH_4$ when treated with a neutral ammonium salt solution after first treating it with an alkaline solution in excess. This method was studied in some detail by Kelley and Brown (4) and has been extensively used in this laboratory.

Kelley (2) then suggested a difference method for the determination of exchangeable H that was described as follows: "****the most accurate measure of base unsaturation referring to the exchange complex, of course, is afforded by first determining the total replaceable bases calculated in terms of chemical equivalents, and then determining the amount of $NH_4$ which the soil will absorb from a neutral ammonium salt solution after the soil has first been treated with an alkaline solution in excess. The difference between the $NH_4$ absorbed and the sum of the replaceable bases originally present affords a measure of the replaceable hydrogen ions which can be expressed in terms of base unsaturation."

This method should give accurate results, but solubility effects make it difficult, if not impossible, to secure accurate determinations of the replaceable bases in many soils. The question arises in con-

[3]Reference by number is to "Literature Cited," p. 1039.

[4]The writer wishes to express his appreciation to these authors for the loan of a copy of their manuscript prior to its publication.

nection with the method as to whether the trivalent bases in the neutral salt extract come into solution as a result of base exchange or as a result of the solvent action of the acid formed in the reaction between the soil and the neutral salt. If the trivalent bases are considered to have been replaced, the sum of the replaceable bases originally present in the soil will be greater, and the content of exchangeable H correspondingly smaller, than if the trivalent bases are considered as non-replaceable. If the method suggested by Kelley could be modified so as to eliminate solubility effects and the question as to whether or not the trivalent bases are exchangeable, it should give very dependable results.

Apparently, for the purpose of eliminating solubility effects and shortening the procedure, Kelley and Brown (4) have modified the method in certain respects. In the modified or $NH_4Cl$ method, exchangeable H is considered to be equivalent to the difference in the amount of $NH_4$ absorbed by the soil before and after treatment with an excess of Ba or $Ca(OH)_2$. In such a method the assumption is apparently made that when an acid soil is treated with neutral $NH_4Cl$, ion exchange is limited to the bases and that there is no exchange of $NH_4$ for the H ion. The writer (5) has shown that such an assumption is erroneous and that on most soils studied their method gives low results.

The first method used, in the present study, for the determination of the exchangeable H content of soils was a modification of the method suggested by Kelley (2). The exchangeable H is considered to be the difference between the exchange capacity of the soil and the content of replaceable bases in the soil. The exchange capacity was determined by treating the soil with an excess of $Ba(OH)_2$ and then determining the amount of $NH_4$ it would absorb from neutral $NH_4Cl$. The content of exchangeable bases was determined by replacing all bases with Ba and then determining the replaceable Ba by leaching the soil with $NH_4Cl$ and precipitating the Ba as $BaSO_4$. When the soil is being leached with $BaCl_2$ to replace the bases, some H is replaced. This is determined by titration of the $BaCl_2$ extract. The mgm. eq. of H replaced is subtracted from the Ba absorbed to give the Ba equivalent of the exchangeable bases in the soil. The detailed procedure follows.

*Exchange capacity of soil.*—Ten grams of soil were treated at room temperature with 100 cc of N/10 $Ba(OH)_2$, for a period of 16 to 18 hours. In the case of soils having a high exchange capacity only 5 grams of soil were used in this and subsequent determinations. The suspension was then filtered by suction in a Gooch crucible. After all of the soil had been transferred to the crucible it was leached with 250 cc of neutral N/1 $NH_4Cl$. The soil and crucible were then carefully washed with ethyl alcohol until free of chlorides. The soil was then transferred to a Kjeldahl flask and the content of exchangeable $NH_4$ determined by distillation with MgO.

*Exchangeable base content of soil.*—Five or 10 grams of soil were placed in a Gooch crucible and leached with 250 cc of neutral N/1 $BaCl_2$. The leachings were titrated with N/10 $Ba(OH)_2$ to determine the amount of H replaced by the Ba. Phenolphthalein was used

TABLE 1.—*Data obtained in the determination of exchangeable H in soils by difference.**

| Lab. No. | Soil type | Leached with N $BaCl_2$ Ba absorbed, mgm. eq. | H replaced, mgm. eq. | Bases replaced, mgm. eq. | Total exchange capacity, mgm. eq. | Exchangeable H in the soil mgm. eq. | Percentage saturation |
|---|---|---|---|---|---|---|---|
| 372 | Norfolk sand | 0.88 | 0.15 | 0.73 | 1.67 | 0.94 | 43.7 |
| 376 | Norfolk sandy loam | 0.76 | 0.20 | 0.56 | 2.58 | 2.02 | 20.9 |
| 379 | Cecil clay loam | 6.05 | 0.05 | 6.00 | 8.22 | 2.22 | 73.0 |
| 386 | Decatur silt loam | 5.27 | 0.15 | 5.12 | 7.93 | 2.81 | 64.5 |
| 387 | DeKalb fine sandy loam | 1.66 | 0.10 | 1.56 | 3.21 | 1.65 | 48.6 |
| 506 | Wooster silt loam | 7.28 | 0.50 | 6.78 | 10.13 | 3.35 | 66.8 |
| 518 | Gray silt loam | 4.67 | 2.60 | 2.07 | 8.18 | 6.11 | 25.3 |
| 548 | Grundy silt loam | 24.74 | 1.90 | 22.84 | 30.30 | 7.46 | 75.5 |
| 555 | Grundy silt loam (limed) | 32.00 | 0.10 | 31.90 | 35.45 | 3.55 | 90.0 |
| 559 | Portsmouth sandy loam | 5.19 | 2.82 | 0.37 | 10.40 | 10.15 | 3.5 |
| 629 | Cecil sandy loam | 1.38 | 0.77 | 0.61 | 4.37 | 3.76 | 13.9 |
| 641 | Susquehanna clay | 31.38 | 24.50 | 6.88 | 34.25 | 27.37 | 20.0 |

*All results are expressed as milligram equivalents per 100 grams of soil.

as the indicator. The soil was then leached with N/1 $NH_4Cl$ until the leachings gave no test for Ba. Barium in the $NH_4Cl$ leaching was determined as $BaSO_4$. Expressed in chemical equivalents, the amount of Ba absorbed minus the H replaced gives the replaceable base content of the original soil.

In the above determination all solubility effects are eliminated in the determination of the exchangeable base content of the soil. The assumption, however, was made that the acidity of the $BaCl_2$ leachings was caused by exchangeable H rather than by salts of trivalent bases that came into solution as a result of base exchange.

This method was used with 12 soils and the results are given in Table 1. The soils ranged from a rather coarse sand with an exchange capacity of 1.67 mgm. eq. to a heavy clay with an exchange capacity of 34.25 mgm. eq. The content of exchangeable H varied from 0.94 mgm. eq. to 27.37 mgm. eq., whereas the degree of saturation varied from 3.5 to 90%. The amount of H replaced by the $BaCl_2$ treatment was, with the exception of soil No. 641, a small percentage of the total content of exchangeable H.

The difference method is fundamental in principle, but it is subject to many errors since it involves several separate determinations and the final result is obtained by difference. It is very tedious and would not be satisfactory for routine work.

## THE TITRATION METHOD

In the study of exchangeable H by the difference method, it was found that soils having a reaction near pH 7.0 contained very little exchangeable H. This seemed to indicate that soils have H in the exchange complex only at reactions below pH 7.0 and that the content of exchangeable H could be determined by titrating a soil to pH 7.0 with a base. The method was, therefore, tried on the same soils that were studied by the difference method.

The method of titration was the dialysis colorimetric method used by Pierre (6) in his work on the buffer capacity of soils. In the method two to three days are allowed for the establishment of an equilibrium between the soil and the added $Ba(OH)_2$. The method was repeatedly checked by the electrometric method with satisfactory agreement. The results obtained with the method are given in the third column of Table 2.

The results are in good agreement with those of the method previously described and given in the last column of the table. It is apparent, therefore, that soils whose exchange complex is saturated with divalent bases, such as Ca or Ba, are neutral in reaction. It also follows that soils with a reaction of pH 7.0 or above do not contain exchangeable H.

The good agreement between the results obtained by difference and the results obtained by titrating the soil to pH 7.0 indicates that the soils do not contain trivalent bases in a replaceable condition. The titration of a soil to pH 7.0 is a neutralization reaction. The base reacts with the exchangeable or acid H with the formation of a Ba

TABLE 2.—*Exchangeable H in soils as determined by titrating the soil to pH 7.0 and by difference.*

| Lab. No. | Soil type | pH of soil | Base required to titrate soil to pH 7.0, mgm. eq. | Exchangeable H by difference, mgm. eq. |
|---|---|---|---|---|
| 372 | Norfolk sand | 5.85 | 0.95 | 0.94 |
| 376 | Norfolk sandy loam | 5.35 | 1.35 | 2.02 |
| 379 | Cecil clay loam | 6.00 | 2.50 | 2.22 |
| 386 | Decatur silt loam | 5.85 | 2.50 | 2.71 |
| 387 | DeKalb fine sandy loam | 5.85 | 1.45 | 1.65 |
| 506 | Wooster silt loam | 5.30 | 3.25 | 3.35 |
| 518 | Gray silt loam | 4.65 | 6.75 | 6.11 |
| 548 | Grundy silt loam | 5.05 | 10.00 | 7.46 |
| 555 | Grundy silt loam (limed) | 6.05 | 3.75 | 3.55 |
| 559 | Portsmouth sandy loam | 4.40 | 10.50 | 10.15 |
| 629 | Cecil sandy loam | 4.55 | 4.00 | 3.76 |
| 641 | Susquehanna clay | 4.80 | 26.65 | 27.37 |

complex and water. There could not be a reaction between exchangeable trivalent base and the $Ba(OH)_2$ added to the soil. Hence, the result obtained does not involve an assumption regarding the presence or absence of trivalent bases in an exchangeable condition.

In the method of difference, on the other hand, the assumption is made that the acidity of the $BaCl_2$ leachings is due to the replacement of H by Ba, and that it is not due to the presence of hydrolyzable salts of trivalent bases that come into solution as a result of ion exchange. Since the results obtained by the two methods agree, the assumption apparently is correct. If the presence of exchangeable trivalent bases were assumed to account for the acidity of the $BaCl_2$ leachate, the results obtained by the method of difference would be, in the case of several soils, considerably different from the results obtained by titration. For instance, soil No. 518 would have 3.51 mgm. eq. of exchangeable H by the method of difference as compared with 6.75 mgm. eq. as determined by titration. The corresponding figures for soil No. 641 would be 2.87 and 26.65 mgm. eq., respectively.

## THE BARIUM ACETATE METHOD

Reference has already been made to the fact that it is apparently impossible to reduce the acidity of a soil to pH 7.0 by continued leaching with $BaCl_2$. An acid soil after continued leaching with neutral $BaCl_2$ will usually have a reaction below pH 6.5. The above is readily explained by the fact that in the exchange reaction HCl is formed and, being highly dissociated, it prevents the replacement of other H. If a salt of a weak acid is used, more complete replacement of H can be effected. When a soil is leached with neutral $Ba(C_2H_3O_2)_2$ and then washed free of the acetate, its reaction will be approximately neutral. This indicates that the Ba of the acetate solution replaces all H in compounds whose ionization would produce an acidity greater than pH 7.0.

In order to study the acetate method in some detail, 5 or 10 grams of each of the 12 soils were placed in a Gooch crucible and leached with 250 cc of neutral N/1 $Ba(C_2H_3O_2)_2$. It is essential that the acetate

solution have a reaction of pH 7.0. The leachings are then titrated with N/10 $Ba(OH)_2$ to pH 7.0. The end-point of the titration is determined electrometrically, using either the H or quinhydrone electrode. The results obtained with the method are given in the second column of Table 3. The third column of the table gives the reaction of the leached soil after having been washed free of acetate.

TABLE 3.—*Exchangeable H in soils as determined by the $Ba(C_2H_3O_2)_2$ method, by titration, and by difference.*

| Lab. No. | Leached with $Ba(C_2H_3O_2)_2$ H replaced, mgm. eq. | Leached with $Ba(C_2H_3O_2)_2$ pH of leached soil | Exchangeable H by titration, mgm. eq. | Exchangeable H by difference, mgm. eq. |
|---|---|---|---|---|
| 372 | 1.20 | 6.95 | 0.95 | 0.94 |
| 376 | 1.45 | 6.87 | 1.35 | 2.02 |
| 379 | 3.50 | 7.25 | 2.50 | 2.22 |
| 386 | 3.65 | 7.17 | 2.50 | 2.71 |
| 387 | 1.50 | 7.02 | 1.45 | 1.65 |
| 506 | 4.00 | 7.17 | 3.25 | 3.35 |
| 518 | 7.00 | 7.10 | 6.75 | 6.11 |
| 548 | 9.10 | 7.15 | 10.00 | 7.46 |
| 555 | 4.20 | 7.20 | 3.75 | 3.55 |
| 559 | 8.85 | 7.05 | 10.50 | 10.15 |
| 629 | 4.00 | 6.90 | 4.00 | 3.76 |
| 641 | 26.60 | 7.10 | 26.65 | 27.37 |

The data presented in Table 3 show that the three methods give very nearly the same result. The small differences may be due to experimental error. The results obtained by the $Ba(C_2H_3O_2)_2$ method show that all of the exchangeable H can be replaced by the Ba of a neutral solution of $Ba(C_2H_3O_2)_2$. The differences in the amount of exchange between the soil H and $Ba(C_2H_3O_2)_2$ and $BaCl_2$ are due, as has been indicated, to the difference in the strength of acid formed as a result of the exchange reaction. The reaction of the soil after leaching with $Ba(C_2H_3O_2)_2$ was in most cases approximately pH 7.0. The fact that in several cases it was somewhat above pH 7.0, was probably due to a slight hydrolysis of the Ba-saturated complex. The reaction of the soil was determined colorimetrically (7) after the suspension had stood approximately 18 hours, thus affording ample time for slight hydrolysis.

Since the exchange complex is saturated with Ba after leaching with the acetate, the exchange capacity of the soil can readily be determined by determining the absorbed Ba or by replacing the Ba with $NH_4$ and determining the absorbed $NH_3$. The recommended procedure follows.

After leaching the soil with 250 cc of N $Ba(C_2H_3O_2)_2$ for the determination of exchangeable H, it is leached with N $NH_4Cl$ to replace the Ba with $NH_4$. The soil is then washed with ethyl alcohol to remove the excess $NH_4Cl$. When free of chlorides, the soil is transferred to a Kjeldahl flask and the absorbed $NH_3$ is determined by distillation. The exchange capacity in mgm. eq. is calculated from the titration figure.

Pierre and Worley, working in this laboratory, have compared this method for the determination of exchange capacity with the $Ba(OH)_2$-$NH_4Cl$ method. They found that, with 20 of the 22

soils studied, the $Ba(OH)_2$-$NH_4Cl$ method gave somewhat higher results. The increase varied from minus 0.91 mgm. eq. to 3.38 mgm. eq. with an average of 0.78 mgm. eq. Precentagely, the increase varied from a minus 2.8 to 35.7, with an average increase of 14.5. Results of a similar nature were secured when the two methods were compared on 6 of the 12 soils used in this investigation. The average exchange capacity of the six soils was 12.24 mgm. eq. by the $Ba(C_2H_3O_2)_2$-$NH_4Cl$ method, and 13.56 mgm. eq. by the $Ba(OH)_2$-$NH_4Cl$ method. These results may be explained by assuming that the $Ba(OH)_2$ treatment attacks the soil particles slightly and increases the exchange capacity of the soil. That this explanation may be correct is indicated by the fact that the more prolonged and drastic the $Ba(OH)_2$ treatment, the higher the apparent exchange capacity.

The 12 soils used in these studies had an average exchange capacity of 12.15 mgm. eq. when the $Ba(OH)_2$ treatment consisted of leaching the soil with 100 cc of N/10 base. If the base and soil were permitted to remain in contact overnight but at room temperature, 11 of the 12 soils gave a slightly higher value for exchange capacity. The average increase for the 12 soils was 0.67 mgm. eq. Boiling the soil with the hydrate for only one minute caused a very marked increase in the exchange capacity. Additional studies of the two methods for exchange capacity are being made in this laboratory by Pierre. The combination of the $Ba(C_2H_3O_2)_2$ method for exchangeable H and the $Ba(C_2H_3O_2)_2$-$NH_4Cl$ method for exchange capacity has been extensively used in this laboratory. It has made the determination of exchangeable H and percentage base saturation relatively simple and rapid.

## THE CONDUCTOMETRIC TITRATION METHOD

The conductometric titration method has been used by several investigators studying soil acidity. In conversation with the writer, Doctor Bradfield suggested that the method might give a measure of the exchangeable H content of the soil. Acting on the suggestion, a careful study of the method was made using 3 of the 12 soils whose content of exchangeable H was known.

In the study the titration was made by two different procedures. In the first procedure a given quantity of soil was placed in 100-cc volumetric flasks and varying quantities of base were added. The conductivity of the resulting suspensions was determined after 5 minutes, and 1, 6, and 24 hours. The titration was carried out using NaOH and $Ba(OH)_2$. This method of titration was unsatisfactory since the end-point of the titration was rather indefinite. When NaOH was used in the titration, it was impossible to secure an end-point. When $Ba(OH)_2$ was used, the end-point was fairly definite in two of the three soils. At certain intervals of time two distinct breaks in the titration curve were obtained with soil No. 518. Soil No. 641 only gave one break and soil No. 559 never gave a definite end-point. The end-points secured by this method varied somewhat with the time interval. With a short interval of time it approximated the results secured for exchangeable H by the other three methods.

The second method of making the titration was by adding varying amounts of soil to a given quantity of base. This procedure was used with both NaOH and $Ba(OH)_2$ and readings made after 1, 8, and 24 hours. In all instances a very definite end-point was obtained. The end-point, however, varied considerably, depending on the time of soil base contact. The content of exchangeable H, as indicated by the end-point secured after a contact of 1 hour, approximated that obtained by other methods. After a contact of 6 hours, the result was uniformly higher. An approximate equilibrium was established after 24 hours and those values are shown in Table 4, together with the content of exchangeable H as determined by difference.

TABLE 4.—*Exchangeable H as determined by conductometric titration and by difference.*

| Soil No. | Base added to soil NaOH, mgm. eq. | Base added to soil $Ba(OH)_2$, mgm. eq. | Soil added to base NaOH, mgm. eq. | Soil added to base $Ba(OH)_2$, mgm. eq. | Exchangeable H by difference, mgm. eq. |
|---|---|---|---|---|---|
| 518 | —* | 13.0 | 10.0 | 13.3 | 6.11 |
| 641 | —* | 33.4 | 23.8 | 30.4 | 27.37 |
| 559 | —* | —* | 15.9 | 19.6 | 10.15 |

*End-point was indefinite.

The results given in Table 4 show that at the point of equilibrium the conductometric method gives high results for the content of exchangeable H. This result is readily explained by the absorption of the base by the soil. Doubtless the base reacts most readily with the exchangeable H and if the reaction stopped at that point the method would indicate the content of exchangeable H. The titrations made at the shortest time interval seemed to approximate this condition. The base, however, as shown by Kelley and Brown (4) continues to react with the soil and is held in a non-exchangeable form. As long as this reaction continues, the end-point of the titration changes, with the result that at equilibrium the titration figure is considerably higher than the content of exchangeable H.

## SUMMARY

A study was made of four methods for the determination of the amount of exchangeable H in soils. The methods were used on 12 soils of widely different texture, origin, and content of exchangeable H. The H content of a soil was assumed to be equal to the difference between the exchange capacity of the soil and its content of exchangeable bases. This difference was determined. Exchangeable H was then determined by titrating the soil to pH 7.0 with $Ba(OH)_2$ by determining the amount of H replaced by leaching the soil with neutral $Ba(C_2H_3O_2)_2$, and by conductometric titration. The results may be summarized as follows:

1. The difference method, titration to pH 7.0, and the $Ba(C_2H_3O_2)_2$ method give similar results for exchangeable H when compared on 12 soils.

2. The conductometric titration method is unsatisfactory for the determination of exchangeable H.

3. Acid soils do not contain an appreciable amount of exchangeable Fe and Al.

4. A tentative method, the $Ba(C_2H_3O_2)_2$-$NH_4Cl$ method, for the determination of exchangeable H is described.

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# 4. METHODS FOR STUDYING REPLACEABLE BASES IN CALCAREOUS SOILS[1]

P. S. BURGESS[2]

## INTRODUCTION

The subject of base replacement is one of especial importance when soils of the arid and semi-arid sections of the earth are being considered, for not only do base-exchange reactions play a vital part in the phenomena of plant absorption, fertilization, and soil acidity correction, which are common to most arable soils, but such reactions are also directly concerned with black-alkali formation and with alkali-soil reclamation. With the importance of base-replacement established, the next logical step has been the perfection of quantitative methods for the determination of the positive ions thus loosely held in soils. The exchangeable bases present in *neutral* and *slightly acid* soils are comparatively easy to replace quantitatively by means of aqueous solutions of $NH_4Cl$, NaCl, or KCl, but soils carrying $CaCO_3$, $MgCO_3$, or dolomite in considerable quantities, or soils high in soluble (alkali) salts, have presented difficulties which, even at the present time, are not fully overcome.

Since it is often desirable to determine exchangeable Na and K, the $NH_4Cl$ solution has been chiefly used as the replacing agent. In calcareous soils, $NH_4Cl$ is unsatisfactory in that it gives rise to several classes of errors. First, where sufficiently large samples of soil are extracted to give proper amounts of Ca, Mg, Na, and K for accurate gravimetric or volumetric determination, and where 0.1N (or stronger) solutions of $NH_4Cl$ are employed, there remains upon evaporation an enormous amount of $NH_4Cl$ which must be gotten rid of before these determinations can be made. This is often accomplished by volatilization, and, as is well known, where the amounts of $NH_4Cl$ are large (many grams) and the amounts of Ca, Mg, Na, and K small (often but a few milligrams), the possibilities of error due to mechanical loss are great. Furthermore, such a procedure is time-consuming and requires constant attention. Repeated evaporation with $HNO_3$, as used in some laboratories for this purpose, is also wasteful of time and disagreeable. The second, and, to us in the arid Southwest, the most important reason for condemning $NH_4Cl$ is that $CaCO_3$ is appreciably soluble in its solutions (280 p.p.m. in 0.1N $NH_4Cl$).

The soils of this section are almost without exception calcareous, carrying from 1 to over 25% $CaCO_3$, hence any solution which appreciably dissolves this salt is of questionable value where replaceable Ca is to be determined. The correct amount of this dissolved Ca cannot be subtracted because equilibrium is seldom attained during replacement. The third reason for condemning the use of $NH_4Cl$ is that the constant presence of dissolved Ca in the replacing solution

[1]Paper read as part of the symposium on "Application of Base Exchange Methods" at the meeting of the Society held in Washington, D. C., November 22, 1928.

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prevents the exchange reaction from going to completion. Another reason which might be added is that aqueous solutions of $NH_4Cl$ dissolve considerable amounts of organic matter from our western, alkaline soils which, as a soil colloid, may itself play a small part in exchange reactions.

In the light of these objections to the $NH_4Cl$ method for the quantitative determination of replaceable bases in calcareous soils, the writer[3] in the spring of 1926 called attention to the possibility of using aqueous solutions of $BaCl_2$. It was shown that the replacing power of Ba considerably exceeds that of $NH_4$ in equivalent solutions, that the carbonates of Ca and Mg are about one-half as soluble in 0.1 N $BaCl_2$ as in 0.1 N $NH_4Cl$, and finally, that soil organic matter is practically insoluble in $BaCl_2$ solutions.

While the method proposed was not all that could be desired, it was far superior to the $NH_4Cl$ method. Also, the difficulties of quantitatively separating the replaced bases from the excess of $BaCl_2$ were overcome. From that time until the present, a considerable amount of work has been done in our laboratories upon different phases of the base-exchange problem. Methods applicable to our calcareous soils naturally have received their full share of attention, and the results of some of these later studies form the subject matter of this paper.

## EXPERIMENTAL

In casting about for pure liquids in which $CaCO_3$ and $MgCO_3$ would be less soluble than in water, the alcohols suggested themselves, and early experiments indicated that base-exchange reactions took place almost as readily in alcoholic salt solutions as in aqueous salt solutions. On the other hand, $BaCl_2$ and $NH_4Cl$ are themselves but slightly soluble in 95% ethyl or methyl alcohol. The question then arose as to the strength of replacing solutions necessary for complete replacement where reasonable volumes of solution were employed. It has been shown repeatedly that base-exchange reactions follow the type equation $X = KC^{1/p}$, where $X$ = the total amount of base, K is a constant, C = concentration of the replacing solution, and $1/p$ is a constant depending upon the slope of the curve (usually less than one-half). This equation shows that doubling the concentration of the replacing solution increases the amount of base replaced but slightly. Experimental verification of this was secured by increasing the concentration of the replacing solution four-fold when the amount of base displaced was increased only 13%, volumes of the solutions remaining constant. This indicated that concentrated replacing solutions were very little more effective than relatively weak ones, which was a most desirable factor if alcohol was to be used.

As our previous work had shown the desirability of using a soluble Ba salt, several series of solubility experiments with $BaCl_2$ and $BaBr_2$ in ethyl and methyl alcohol of different concentrations were

[3]BURGESS, P. S., and BREAZEALE, J. F. Methods for determining the replaceable bases of soils either in the presence or absence of alkali salts. Ariz. Agr. Exp. Sta. Tech. Bul. 9. 1926.

made.[4] These data showed that 0.1 N solutions of $BaCl_2$ can be made up at ordinary laboratory temperatures in 68% ethyl alcohol or in 80% methyl alcohol, and that 0.1 N solutions of $BaBr_2$ can be obtained in 92% ethyl alcohol or in 95% methyl alcohol. The solubilities of C. P. $CaCO_3$ and basic $MgCO_3$ in these alcoholic salt solutions were then determined, and it was found that, at 20°C, the solubilities expressed as p.p.m. of Ca and Mg were as follows:

| | $BaCl_2$ EOH | $CaCl_2$ MOH | $BaBr_2$ EOH | $BaBr_2$ MOH | $CaCl_2$ $H_2O$ |
|---|---|---|---|---|---|
| $CaCO_3$ | 14 | 11 | 15 | 141 | 72 |
| $MgCO_3$ (basic) | 229 | 131 | 110 | 239 | 442 |

These solubilities indicate that $BaCl_2$ in either ethyl or methyl alcohol should be the best displacing agent for soils carrying $CaCO_3$, and that $BaBr_2$ in ethyl alcohol should be the best in the presence of basic $MgCO_3$.

As many investigators prefer to use ammonium salt solutions for displacement purposes, the possibilities of alcoholic solutions of $NH_4Cl$ were investigated. Normal solutions of this salt can be made in 70% ethyl alcohol and in 75% methyl alcohol at 20°C. The solubility of $CaCO_3$ in the former is 46 p.p.m. Ca, and in the latter 60 p.p.m. Ca. Precipitated basic $MgCO_3$ gave solubilities of 180 and 548 p.p.m. Mg, respectively. It should be stated at this point that precipitated $MgCO_3$ is very much more soluble than the naturally occurring magnesite or dolomite, even though the latter may be very finely ground. This is not true where precipitated $CaCO_3$ and finely ground calcite or limestone are compared. Here the solubilities are similar. We are also finding that $MgCO_3$ in soils acts very differently from $CaCO_3$ in base-exchange reactions. This subject is at present being investigated in our laboratory.

The speed and completeness of reaction in aqueous and alcoholic solutions of $BaCl_2$ and $NH_4Cl$ was next studied, and it was found that the rate of replacement in ethyl-alcohol solutions was very nearly equal to that in water solutions, while in methyl alcohol it was somewhat less. Also, practically identical total amounts of replaceable bases were secured by all methods, showing the feasibility of using any of the replacing solutions where neutral or acid soils were being studied. These statements held for both $BaCl_2$ and $NH_4Cl$. Both artificial Ca zeolite and non-calcareous soils of known base-exchange capacities were used in this work. I will not burden my readers with the details of these experiments for they have been published elsewhere.[5]

In the light of the foregoing, we decided to concentrate our efforts on the use of 0.1 N $BaCl_2$ in 68% ethyl alcohol; first, because these two substances were cheaper than $BaBr_2$ and methyl alcohol; second, because $CaCO_3$ was slightly less soluble in the ethyl alcohol solutions; and third, because the replacement reactions proceeded somewhat

[4]All of the data appear in a publication by O. C. Magistad and P. S. Burgess on "The use of alcoholic salt solutions for the determination of replaceable bases in calcareous soils." Ariz. Agr. Exp. Sta. Tech. Bul. 20. 1928.

[5]*Loc. Cit.* (p. 485–490).

more rapidly here than where methyl alcohol was employed. Some work also was done with $NH_4Cl$ dissolved in ethyl alcohol.

To one of the neutral, non-calcareous soils of known exchangeable-base capacity mentioned above was added 4% of C. P. $CaCO_3$ powder. A series of percolation tubes, each containing 25 grams of this mixture, was leached repeatedly with 250-cc portions of the two alcoholic and the two aqueous salt solutions. Here we have the unusual situation of knowing the correct base exchange capacity of a calcareous soil and can find the exact amounts of Ca dissolved by each replacing solution from the excess of $CaCO_3$ present. Thus, in the five 250-cc portions used in each case 0.0239, 0.0077, 0.1807, and 0.0374 gram of Ca were dissolved by the 0.1 N $BaCl_2$ in water and in alcohol and the N $NH_4Cl$ in water and in alcohol, respectively. These figures are equivalent to 19, 6, 144, and 30 p.p.m. Ca in the solutions, whereas the solubilities at equilibrium are 60, 14, 200, and 47 p.p.m. Ca, respectively. We thus see that the $BaCl_2$ solutions were less than one-half saturated, while the $NH_4Cl$ solutions were approximately two-thirds saturated. Obviously, it is impossible to determine the correct solubility blanks to be subtracted from the total Ca found where replaceable Ca is being determined by leaching methods, but where this blank amounts to only 6 p.p.m., as is the case of $BaCl_2$ in ethyl alcohol, the least chance for error arises and in routine work may be neglected.

Most of the foregoing experimental work was done by the percolation method. The several solutions were also compared, using the shaking and filtering method. Here the Ca blanks, which were small in the alcoholic solutions, approached equilibrium and could be subtracted more safely from the total Ca found in the solutions. The amounts of replaceable Ca were very similar to those secured by the percolation methods.

Some study was also given to the fact that bases may be dissolved from soil minerals other than carbonates by replacing solutions, but a series of solubility determinations in the alcoholic solutions, using finely ground soil minerals, indicated that such errors were slight.

## METHOD ADOPTED

The method finally adopted for routine work with calcareous soils is as follows: Fifty grams of the air-dry soil (25 grams or less if high in clay) are placed in a pyrex-glass percolating tube and leached with 500 cc of 0.1 N $BaCl_2$ in 68% ethyl alcohol. With light, sandy-loam soils it is often necessary to limit the rate of flow of the alcoholic solution by means of a rubber tube and pinch-cock, for alcohol, due to its lower surface tension, percolates more rapidly than does water. Additional 100-cc aliquots are percolated through the soil column until the amount of Ca found in the percolate drops to the solubility of $CaCO_3$ in the displacing solution (6 or 8 p.p.m. Ca). Less than 1 liter is usually required. The total percolate is evaporated to dryness, taken up in warm water, made up to volume (250 cc), and the replaced bases determined as set forth in detail by Burgess and Breazeale.[6]

[6]*Loc. Cit.* (p. 197–199.)

Soils containing soluble salts (alkali) must first be leached with pure water until free from such materials. A little waxy matter may be dissolved from the soil by the alcohol, but it does not appear to interfere with the determinations. Also, the small cost of ethyl alcohol, when duty free, makes it unprofitable to recover it by distillation. Ordinarily, it is unnecessary to subtract the small amount of Ca dissolved from the soil $CaCO_3$ by the alcoholic displacing solution, but it may be approximated if desired. Heavy clay soils sometimes percolate very slowly, but little of the analyst's time is required except in making the actual determinations.

When small numbers of determinations are required, shaking or digesting with subsequent filtration may be substituted for percolation. Here, 25 or 50 grams of the soil, depending upon the zeolite content, are shaken with 500 cc of the alcoholic displacing solution, filtered through paper, and washed with fresh portions of the solution until free from replaceable Ca. The filtrates are evaporated to dryness, taken up in warm water, and the analyses made as above.

I cannot let this opportunity pass without speaking a good word for the soap-titration method where large numbers of Ca and Mg determinations are to be made. While this method of Clarke has long been used in the analysis of potable waters and was applied to soils work years ago by the U. S. Bureau of Soils, it was Breazeale who introduced it into our laboratories. A certain amount of experience is required in familiarizing one's self with the method as it is not "fool proof," but when the proper technic has been developed, it is a very accurate and a very rapid method. We often have compared it with the standard volumetric and gravimetric methods and do not hesitate to recommend it, except where Mg exceeds Ca in amount (which seldom occurs in soils work) or where the solution is very concentrated with respect to these ions. An account of the method is given in Arizona Agr. Exp. Sta. Tech. Bul. 9.

## CONCLUSIONS

The need of methods for the accurate determination of replaceable bases in calcareous soils is pointed out, and some of the faults of the earlier procedures, when applied to soils containing $CaCO_3$, are discussed.

The method which is proposed for the quantitative determination of replaceable bases in calcareous soils employs alcoholic salt solutions as the displacing agents. We prefer 0.1 N $BaCl_2$ in 68% ethyl alcohol. Percolation, rather than shaking with subsequent filtration, is advocated where large numbers of determinations are to be made. The alcohol is evaporated, the residue is taken up in water and made up to volume, the excess Ba is precipitated as the chromate where Ca and Mg are to be determined or as the sulfate where Na and K are sought. Subsequently, the bases are separated by appropriate methods. Where "alkali salts" are present, these are removed by leaching with pure water before the soils are treated with the replacing solutions.

# 5. THE USE OF ARTIFICIAL ZEOLITES IN STUDYING BASE EXCHANGE PHENOMENA[1]

O. C. MAGISTAD[2]

The intensive study of base exchange, using soil material, is hampered by the fact that the compounds or absorbing complexes responsible for exchange phenomena cannot be isolated in pure form. Isolation of soil colloids has concentrated these complexes, but soil colloids obtained by the best methods, still contain foreign material of the same general chemical composition as the zeolites themselves, such as Al, Si, and partially decomposed rock fragments. Studies with exchangeable bases, including H, have shown that synthetic zeolites and the base exchange complex in soils act in a similar manner.

If we could be certain that the synthetic zeolite studied in the laboratory is identical with the base exchange complex in soils, or that it acts in the same manner quantitatively as well as qualitatively, research on base exchange could be greatly accelerated by the use of these pure synthetic zeolites. On account of the foreign material present in soils, it is sometimes impossible to obtain quantitative checks between soils and synthetic zeolites, but qualitative or semi-quantitative checks are nearly always possible. Such checks should always be sought. This has been the general method of study at the University of Arizona.

The use of synthetic zeolites for the study of base exchange problems is particularly desirable in certain phases of work; for example, in those problems where the intake and outgo of any particular element, such as Al, common to the zeolite and to the non-zeolitic soil material, is desired. The similarity of action in soil zeolites and synthetic compounds will be discussed later.

## PREPARATION OF SYNTHETIC ZEOLITE

The literature abounds with methods for the preparation of zeolites. For their synthesis, two general procedures are available, *viz.*, the fusion method studied by Gans (11, 12)[3] and originally used in the manufacture of permutites, and the wet method in which the ingredients are simply mixed together in solution and the resulting gel washed, dried, and ground.

In our work at Arizona, only zeolites made by the wet process have been used. We have done this because such compounds correlate well with soil zeolites in their action and because we feel that the greater part of soil zeolites are formed by this wet process. Especially does this seem to be true in alkali soils.

[1]Paper read as part of the symposium on "Application of Base Exchange Methods" at the meeting of the Society held in Washington, D. C., November 22, 1928. Contribution from the Department of Agricultural Chemistry and Soils, Arizona Agricultural Experiment Station, Tucson, Ariz.

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[3]Reference by number is to "Literature Cited," p. 1055.

The synthesis of zeolites is described by Burgess and McGeorge (8), but several improvements have since been made. According to the equation:

$$6\,Na_2SiO_3 + 4\,NaAlO_2 + 6\,H_2O \rightleftharpoons 2\,Na_2O.2Al_2O_3.6SiO_2 + 12\,NaOH$$

six mols $Na_2SiO_3$ react with 4 mols $NaAlO_2$ to form 1 mole zeolite closely approaching the theoretical composition of Natrolite. It is desirable to use a slight excess of $Na_2SiO_3$. In this laboratory, 11/10 the theoretical quantity is used. The gel, after standing a few hours, is filtered on a large Buechner funnel, and washed and filtered repeatedly. Ordinary water glass can be used in place of the pure $Na_2SiO_3$ if its Fe content is very low. Sodium carbonate present as an impurity is removed in the first few washings. The zeolite is washed until it no longer contains carbonates and till the hydroxyl-ion concentration of the wash water is not much greater than that accounted for by hydrolysis of the zeolite. Eight to ten washings will usually reduce the alkali content to 10 cc 0.02 N per 100 cc filtrate which is satisfactory. Prolonged washing causes too much hydrolysis of the zeolite and lowers its base content.

Sodium zeolite can be converted into the other desired zeolites by leaching with the appropriate salt solution and washing. In case Ca, Mg, or Ba zeolites are desired, this leaching can take place as soon as the carbonates are removed from the Na zeolite. In the preparation of these derivatives, care should be taken not to expose the materials to $CO_2$ unnecessarily. If the operations are carried on rather rapidly, no special precautions are necessary.

In the above manner Na, K, $NH_4$, Ca, Mg, and Ba zeolites have been prepared. Their composition, except in the case of Mg zeolite, agreed fairly well with the theoretical, except that the base content was always slightly low, due to hydrolysis. The physical condition of the zeolite seems to affect the chemical properties, such as hydrolysis, to a certain degree. Different lots of Na zeolite, for instance, varied about 10% in their hydrolysis constants.

## IDENTITY OF SYNTHETIC ZEOLITES COMPARED TO SOIL ZEOLITES

Gans (11, 13) was one of the earliest and most ardent supporters of the view that soil zeolites are identical with, or very similar to, synthetic permutites. His proof is summarized by Gedroiz (14) as follows:

"1. The data of hydrochloric acid extractions show the composition of silicates decomposed by the acid: 3 (or more) mols $SiO_2$: 1 mol $Al_2O_3$: 1 mol base, i.e., produce an aluminate-silicate only when these silicates are protected against decomposition by the presence of carbonates of alkali earths (neutral or alkaline soils).

"2. These data show less base than 1 mol for every mol. $Al_2O_3$, when they are decomposed by acid (carbonated) solutions as in the process of weathering; the relation between $SiO_2$ to $Al_2O_3$ remains 3 (or more) to 1 (in acid soils).

"3. The data of hydrochloric acid extractions show a lower content of $SiO_2$ than 3 mol. for 1 mol $Al_2O_3$, if the solutions of the decomposing material have an alkaline reaction, as a result of which a part of $SiO_2$ is washed out. Due to the low content of silicic acid, these silicates cannot contain more than 1 mol. of base for 1 mol $Al_2O_3$ (neutral or alkaline soils); with a lower content of base they have an acid nature."

Gedroiz does not deny the theory of Gans, but believes it to be insufficiently supported. Recently, Kerr (19) isolated the silt fraction of a soil and subjected it to mineralogical analysis by the microscopic method. Leverrierite, whose calcium derivative would probably be $CaO.\ Al_2O_3.3\ SiO_2.2\ H_2O$, was found in fairly large quantities. This silt fraction had a base exchange capacity of 6.1 mgm. eq. per 100 grams. Kerr does not claim that Leverrierite is the zeolite responsible for base exchange in all soils, but it does seem to have been responsible for a large portion of the base exchange capacity in this particular soil.

In strongly alkaline soils, solutions of $NaAlO_2$ and $Na_2SiO_3$ are present. With fluctuations of water content, zeolites could easily be formed, as indicated by the work of Burgess and McGeorge (7, 8). Zeolites so formed are largely amorphous, but they could possibly pass over into crystalline forms with time, even at ordinary temperatures and pressures. It is significant that Bradley (3) found beds of crystalline Analcite in the Green River formation of Utah and Colorado. He states that these zeolites must have been made at ordinary temperatures and that there is a strong possibility that these crystalline zeolites were obtained from amorphous ones. Ross (29) also describes Analcite beds and states that it is evident that the zeolite was formed by direct chemical precipitation or more probably by reactions between salt solutions and clay material.

In 1927, the author put aside, in an open Erlenmeyer flask, a concentrated water extract of a synthetic Ba zeolite. Several months later small crystals 1 to 4 mm long were discovered, which, upon analysis by Dr. R. J. Leonard of the Geology Department, University of Arizona, were found to be Eddingtonite. This confirms the possibility of formation of crystalline zeolites at ordinary pressures and temperatures and shows how our amorphous zeolites in soils may gradually change into crystalline ones.

## THE ZEOLITE NUCLEUS AND NATURE OF UNION

Much of our knowledge concerning the base exchange complex, its nucleus, and its base-to-nucleus bonds, has been discovered using synthetic zeolites and permutites rather than soil compounds. It is believed by most soil workers that the soil zeolites or base-exchange complexes are colloidal in nature, although Kerr (19) showed that Leverrierite, a crystalline zeolite, was present in a Colby silt loam.

It has been established, largely by German workers using permutites, that Li, Na, K, Rb, $NH_4$, Ag, $Tl^+$, Mg, Ca, Ba, Mn, $Fe^{++}$, Pb, Cu, and Zn are all replaceable. We have no proof, as yet, that any of the trivalent elements replace other cations in zeolites. The

author has been unable to replace divalent bases with Al, $Fe^{+++}$, and $Cr^{+++}$ in zeolites (20). It is significant that Gunter-Schulze (17) obtained practically no conductivity with his so-called Al, Cr, and Fe permutites.

The nature of the bond is explained by Oden (23) in the following manner. Soil particles can be considered as fragments of crystalline mineral matter, in which the recent researches of Bragg and others have shown an orientation of the atoms with bonds extending from each atom to others in five directions at right angles to each other. On the surfaces, free valences result and these are available and act in base-exchange reactions.

This conception of Oden's explains absorption on crystalline non-zeolitic surfaces and could probably be extended to amorphous non-zeolitic materials. The absorption on such material is only a few per cent of that found in an equal weight of zeolite, however. In soils we can conceive of a relatively large base exchange caused by zeolites and a small base exchange caused by surface reactions on material of other composition, such as quartz, alumina, finely divided feldspar, etc.

The amount of base exchange as found on freshly prepared $Al_2(OH)_3$ was 0.123 mgm. eq. per gram compared to about 4.0 mgm. eq. per gram of zeolite. The base exchange or adsorption on Al is, therefore, about 3% as great as with zeolitic material.

In case of crystalline zeolites, the base is held by major bonds just as in a NaCl crystal. The openness of the lattice allows entering basic ions to reach the exchange portion of every molecule in the zeolite. If we assume that, in these unit cells, the zeolite is partially hydrolyzed, we can see that base exchange can readily occur. Winchell (33) states that base exchange occurs more readily in the highly hydrated zeolites. In amorphous zeolites the process is similar, but the exchange portion of each molecule is nearer the outside solution and can be acted upon more quickly.

Trenel (32) holds that, in the case of unsaturated soils, the cations lost have not been replaced by H ions; a cation vacuum exists.

Little work has been done on the possibility of other elements being substituted for Al in the nucleus of the zeolite. From the analysis of soils and their base exchange capacity, Smolik (30) concludes that an intimate relation exists between Fe and Al in zeolitic silicates, indicating the ability of Fe to substitute for Al to a greater or less degree. The correlation between the ratio $\frac{SiO_2}{Al_2O_3 + Fe_2O_3}$ and the ratio $\frac{SiO_2}{CaO + Na_2O}$ and properties of soil colloids, as found by Robinson and Holmes (27), suggests the possibility of $Fe_2O_3$ taking the place of Al in the zeolite. Thus, Anderson and Matteson (1) obtain a correlation coefficient of 0.90 between the ratio $\frac{SiO_2}{Al_2O_3 + Fe_2O_3}$ and $NH_3$ absorption.

Using the analyses of these soils as given by Robinson and Holmes, the author calculated the coefficient of correlation between the ratio $\frac{SiO_2}{Al_2O_3 + Fe_2O_3}$ and $NH_3$ absorption. Using the analyses of these soils as given by Robinson and Holmes, the author calculated the coefficient of correlation between the ratio $\frac{SiO_2}{Al_2O_3}$ and $NH_3$ absorption, and obtained the value 0.92. This indicates that the ratio $\frac{SiO_2}{Al_2O_3}$ correlates better with $NH_3$ absorption than does the ratio, $\frac{SiO_2}{Al_2O + Fe_2O_3}$, and that $Fe_2O_3$ may not take the place of Al in the zeolite nucleus. By leaching synthetic zeolites with alcoholic solution of $FeCl_3$, the author has succeeded in removing practically all of the Al and depositing $Fe_2O_3$. Such zeolite residues are no longer active, however, nor can they be made active even in alkali solutions. In other tests, $Na_2SiO_3$ solutions were added to acid ferric salt solutions and the precipitate washed and dried. This precipitate did not become active even when treated with alkaline solutions. In summary, no evidence exists that $Fe_2O_3$ can take the place of $Al_2O_3$ in an active zeolite nucleus, although numerous attempts have been made to cause this substitution (20, 22).

The possibility of $Cr_2O_3$ taking the place of $Al_2O_3$ in an active zeolite has also been investigated by the author. A synthetic zeolite leached with an alcoholic solution of $Cr(NO_3)_3$ lost most of its alumina, with the deposition of Cr, but this zeolite residue was no longer active. Attempts to make a synthetic zeolite with $Cr_2O_3$ in the nucleus were then made by adding $Na_2SiO_3$ to $Na_2CrO_4$. The precipitates obtained were only 2 to 5% as great as when $NaAlO_2$ is used. The base exchange capacity of these precipitates exceeded slightly that due to Al impurities. One such zeolite containing equal molar quantities of $Cr_2O_3$ and $Al_2O_3$ had the following molar relationships: 0.855 $Na_2O$:1.00 mol $Al_2O_3 + Cr_2O_3$ : 3.06 mols $SiO_2$. These experiments are not conclusive proof that Cr can take the place of Al; they merely suggest a possibility. From their position in the periodic table, we could hardly expect Fe or Cr to replace Al in the zeolite nucleus. The substitution of B for Al would be more logical. Experiments with B are now in progress.

## RATE OF REACTION AND ATTAINMENT OF FINAL EQUILIBRIUM

Replacement in crystalline zeolites seems to defy the rule that the atomic domain, or size, of the entering atom must approximate that of the atom replaced (34). Thus, two Na's will take the place of previously held Ca, although the volume of the two Na's is over twice as great (35). Crystal lattice studies of crystalline zeolites are almost wholly lacking, that of Gruner (16) being the only one familiar to the author. Such studies might furnish data showing the distances between atoms to be greater than in ordinary substances and thus explain the relatively easy entrance of displacing cations. Exchange in crystalline zeolites must depend on diffusion.

Diffusion progresses slowly, and it is no wonder that Church (10) required three years for the production of silver Phillipsite at ordinary temperatures. Kerr (19), on the other hand, indicates that substitution, in coarse crystalline material, of H for Ca is fairly rapid. This is partially explained by the small size of the H ion. Using a crystal of natrolite of 1.41 grams, the author attained only 3.6% of exchange in two days, the reacting solution containing 3.57 mgm. eq. of Ca compared to 7.41 mgm. eq. of Na held by the crystal. Such exchange is very slow compared to the exchange in synthetic Na zeolite where the reaction went 98.5% to completion under the same conditions. The rapid exchange in amorphous synthetic material is undoubtedly due to the fact that practically all the base is present on the outside, or only a very short distance from the bathing solutions. The openings in the amorphous material may also be considerably larger and very little diffusion need take place for complete exchange.

In the case of synthetic amorphous zeolites there is a slow time effect superimposed on the rapid initial effect. This is well illustrated by the data of Gedroiz (15). It is explained by the presence of cations within the material and at a slight distance from the replacing solution. In order that base exchange of these cations can occur, diffusion for short distances must take place.

## ZEOLITE BREAK-DOWN

Several investigators (4, 9, 20, 26) have noticed that the base exchange capacity of a soil is not a constant, but usually decreases with each neutral salt treatment, with acid treatments, or with prolonged washing with water. This is not caused by solution or a mechanical loss of material, since the exchange capacity per gram gradually decreases.

The author began leaching 120 grams of Na zeolite with 1,500-cc portions of water. At the beginning of the test this zeolite contained 0.903 mol $Na_2O$ per mol. $Al_2O_3$. Subsamples of zeolite were removed at intervals, and complete chemical analyses of them were made. The amount of replaceable H present was determined by the difference method. The samples were leached with 0.1 N $Ba(C_2H_3O_2)_2$, washed, and leached with 0.05 N HCl. The exchangeable Ba so obtained should be equivalent to the sum of the exchangeable Na plus H present. The data are given in Table 1.

These data show that when a Na zeolite is leached with water, a substitution of H ions for Na ions takes place. The H zeolite so formed breaks down, probably with a splitting off of water. The percentage breakdown is given in the last column of Table 1. Such a breakdown of H zeolite decreases the total base exchange capacity of the zeolite.

In another test in which a series of Na zeolite samples were treated with varying quantities of HCl, the H zeolite formed was, in every case, partially broken down.

A soil recently electrodialyzed and having a pH value of about 4.0, was found to be nearly neutral after standing several months in

TABLE 1.—*The hydrolysis of Na zeolite and the break-down of the H zeolite so formed in mols exchangeable base, as oxide, per mol $Al_2O_3$.*

| Leaching interval | W Total beginning interval | S Exchangeable Na at end | W—S Exchangeable H formed | W' Total at end of interval | W'—S Exchangeable H at end of interval | W—W' H zeolite broken down | $\frac{100 (W-W')}{W-S}$ Percentage H zeolite broken down |
|---|---|---|---|---|---|---|---|
| 1–13 | 0.903 | 0.816 | 0.087 | 0.824 | 0.008 | 0.078 | 89.7 |
| 13–17 | 0.824 | 0.768 | 0.056 | 0.796 | 0.028 | 0.028 | 50.0 |
| 17–27 | 0.796 | 0.437 | 0.359 | 0.443 | 0.006 | 0.353 | 98.4 |
| 27–37 | 0.443 | 0.347 | 0.096 | 0.352 | 0.005 | 0.091 | 94.7 |
| 37–47 | 0.352 | 0.176 | 0.176 | 0.175 | none | 0.176 | 100.0 |

water. Trenel (32) and Breazeale (5) have also observed decreases in acidity of H zeolites on standing. These few examples, typical of many in our laboratory, have led to the following hypothesis:

Hydrogen zeolite, by a splitting off of water or a shifting of bonds, forms a zeolite anhydride or lactone-like body. This product is in equilibrium with the H zeolite. Similar cases are known in both inorganic and organic chemistry. The reaction between HCl and Na zeolite could then be illustrated by the following equations:

$$\text{Na zeolite} + \text{HCl} \rightleftharpoons \text{NaCl} + \text{H zeolite}$$

$$\text{H Zeolite} \rightleftharpoons H_2O + \text{anhydride or rearrangement product}$$

$$\downarrow\uparrow$$

$$H^+ + \text{zeolite}^-.$$

It is well known, that the $Ba(C_2H_3O_2)_2$ method usually gives higher values for replaceable H in soils than does the $BaCl_2$ method. Even after prolonged leaching of the acid zeolite with $BaCl_2$, the values are never as great as with $Ba(C_2H_3O_2)_2$. Many claim that low results obtained with chlorides are caused by the fact that HCl is formed as a product of the reaction. Its high degree of ionization, compared to that of the H zeolite or $CH_3$ COOH, allows the reaction to go only a short way towards completion. Using acetates, $CH_3$ COOH is formed as a product and its low ionization permits the reaction to proceed almost to completion.

The low results obtained by $BaCl_2$ also can be explained from the standpoint of the anhydride; H zeolite equilibrium. Here a highly ionized acid decreases the ionization of H zeolite and forces the reaction toward the anyhdride form. Slightly ionized acids permit the anhydride to be converted into H zeolite at a greater rate.

If we consider that the equilibrium between H zeolite and its anhydride is not attained rapidly, it explains the observations of Trenel, and of the author, on an increase in pH values of acid zeolites on standing.

## ZEOLITE BUILD-UP

A number of investigators, including Askinasi and Jarusow (2), Gans (11), Hissink (18), Prianishnikov and Golubev (25), Prianishnikov and Askinasi (26), and Mattson (22), have observed that the

base exchange capacity of a soil depends on the pH value of the displacing solution used. They assume that the increased capacity at the more alkaline reactions is due to an increased liberation of H from the zeolite complex because the quantity of other cations removed remains constant when the pH value of the replacing solution is varied. Some of the H is easily replaced by solutions, such as neutral $BaCl_2$. This quantity the European investigators designate as "exchange acidity." Additional H is liberated by alkaline reagents and salts of weak acids, such as $Ba(C_2H_3O_2)_2$. The quantity liberated is designated as "hydrolytic acidity."

The variation in the base exchange capacity of a soil as determined by a salt solution at various pH values has recently been studied in our laboratories. It seemed logical to us, in view of the fact that we usually work with alkaline soils and reactions permitting soluble silicates and aluminates to be present, to attribute this increased exchange capacity at the more alkaline reactions to an increased quantity of zeolite material rather than a more complete conversion of the H zeolite to a zeolite containing a base such as Ba or Na. Our studies and views have been described by Breazeale (5), Breazeale and Magistad (6), and Burgess (9). Arguments in favor of this view (build-up) as opposed to a more complete liberation of H from the H complex at the more alkaline reactions (hydrolytic acidity) are as follows:

1. There seems to be some evidence in favor of a break-down of H zeolites into a non-acid form. This change is reversible, in part at least, and the reverse reaction can be designated as build-up, or re-formation of the exchange complex.

2. Substances having no exchange capacity can be made highly active by treatment with alkaline solutions at ordinary temperatures. Thus, the author has mixed finely divided $SiO_2$, $Al_2O_3$, and $CaCO_3$ together and after percolation with ordinary salt solutions the system has acquired a measurable base exchange capacity. The base exchange capacity of finely divided orthoclase is greatly increased when digested with alkaline solution, as found by Breazeale and Magistad (6). Rosenheim (28) produces permutites or water softeners by the treatment of various rocks by acid and alkalies, with and without pressure. Evidently, in these cases, no H complex was previously present and build-up must have taken place.

3. The effect of time in base exchange reactions involving H. Base exchange reactions in which the cations involved are metals, alkaline earths, or alkalies are almost instantaneous. The reactions practically go to completion in 30 seconds. This indicates that almost all the replaced cations were on the outside and free to react instantaneously. Treatment with a weak acid places H ions where these cations previously were. One would expect the H ions to be replaced with equal rapidity, but actual tests show that the H ions are released far more slowly.

To demonstrate this point, the author treated 50-gram samples of two acid soils with 500-cc portions of 0.1 N $Ba(OH)_2$ for varying intervals of time. The soil samples were then filtered, washed with 100 cc of distilled water, 500 cc of 0.1 N $BaCl_2$, and washed till the

leach water no longer contained chlorides or Ba. The exchangeable Ba was now replaced with 0.05 N HCl, the Ba precipitated as $BaSO_4$, and weighed. The results obtained are given in Table 2.

TABLE 2.—*Effect of time on the base exchange capacity of soils using 0.1 $Ba(OH)_2$ as the replacing solution.*

| Soil | pH value original soil | Base exchange capacity in mgm. eq. per 100 grams soil when treated 5 minutes | 6 hours | 2 days | 4 days | 7 days |
|---|---|---|---|---|---|---|
| Kentucky silt loam.. | 6.16 | 9.72 | 10.80 | 13.72 | 13.48 | 13.62 |
| New Jersey loam.... | 6.59 | 9.54 | 9.46 | 11.62 | 11.68 | 11.66 |

The data in Table 2 show that the base exchange capacity of the soil is much greater after having been treated for 4 or 7 days with $Ba(OH)_2$ than when treated only 5 minutes. If we assume that the increased capacity at 4 days over that at 5 minutes is caused by a greater liberation of H ions, we have a marked difference in speed of reaction when Ca and H are the replaced ions. Since these ions occupy exactly the same position in the zeolite complex, why do we have this difference in rate of replacement?

On the other hand, if we assume that the increased capacity at the end of several days is caused by an increase in the quantity of exchange material, the explanation is simple. Reactions such as the formation of zeolites by the interaction of soluble aluminates and silicates go on very slowly because of the low solubility of one or more of the constituents at the pH values used. The reaction is somewhat similar to that between $BaCO_3$ and $CaSO_4$. This reaction will progress with the formation of $BaSO_4$ and $CaCO_3$, but at a very slow rate because of the low solubility of the reacting salts. On this basis we should expect an increased base exchange capacity of soils when determined with the more alkaline solutions and also an increase with the time this solution is permitted to react. Both of these statements are found to be true in the case of soils at alkaline reactions.

The significance of zeolite break-down and build-up certainly has not heretofore been appreciated. Our investigations point out the fact that the base-exchange capacity of a soil is not a constant but varies with several factors, such as salt content, pH value, and degree of moisture. The determination of exchangeable H and other bases needs revision if the exchange capacity varies with the pH value and buffer capacity of the replacing solution and the time it is permitted to react. This undoubtedly explains why the various methods for the determination of acidity or total base exchange capacity have given different results.

The phenomenon of break-down must be considered wherever H zeolite is formed, and probably accounts for the low total base exchange capacity of many of our acid, eastern soils. Build-up explains how our alkaline, western soils have obtained such a high exchange capacity. These two processes in a given soil are always in dynamic equilibrium and this equilibrium determines the base-exchange capacity of the soil at the time.

In order to gain a proper understanding of base exchange phenomena, these two processes should be investigated further, and the mechanism of the reactions, as well as the conditions governing them, determined. Synthetic zeolites will lend themselves to such investigations.

## HYDROLYSIS OF ZEOLITES

If solubility determinations of synthetic Na zeolite, for instance, are attempted, one will soon find that the solution contains more base than is indicated by the dissolved Al and Si, and also that the amount dissolved varies with the ratio of water to solid matter. In fact, we are not dealing with solubility, but rather with hydrolysis. It has been shown that synthetic Na and K zeolites hydrolize according to a definite law (21). Potassium zeolites in soils also appear to hydrolize according to this law. This explains why K in the soil solution remains fairly constant, yet does vary in a regular manner with the ratio of water to exchangeable K present in the soil. Sodium zeolite hydrolizes much more readily than does K zeolite and explains the differential rate of leaching. Schreiner and Failyer (31), working with soils practically saturated with K, found that the rate of loss of K by leaching with water was proportional to the amount still remaining. This process is mathematically expressed by the differential equation: $\frac{dy}{dv} = K\,(A\text{-}y)$, where K is a constant, A the maximum quantity the soil can absorb, and y the amount already lost. Further work by Patten and Waggaman (24) substantiated the findings of Schreiner and Failyer and showed that the rate of K absorption also conformed to this same differential equation.

Recent unpublished work by the author, using Na and K zeolites, shows that here also the rate of loss by leaching follows a differential equation of the same type. In its integrated form, this differential equation should give us the loss of K in the leach water from a certain area with a given rainfall or irrigation, provided that no solubility of other potash minerals takes place.

## SUMMARY

Because of their purity, synthetic zeolites are better working materials for base-exchange-reaction studies than soils. In order to make certain that the results obtained apply to soils, qualitative tests at least should be made. Synthetic zeolites, made by the wet method, and soil zeolites behave in a similar manner, although they have not been proved identical. Crystal lattice studies should help to explain base exchange in zeolite crystals, as well as the rate of base exchange in crystalline and amorphous zeolites. Cations are held to the zeolite nucleus by primary bonds. Only two such bonds exist adjacent because substitution of trivalent cations for the exchangeable base in the zeolite has not been obtained. Iron cannot take the place of Al in the nucleus, but Cr may possibly do so. The base exchange capacity of a soil is not a constant, but varies with reaction, moisture, and other factors. Build-up and break-down explain these variations. Sodium and K zeolites hydrolize according to a definite law, and on leaching, the amount removed can be expressed by a mathematical equation.

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## EFFECT OF HARVESTING WHEAT AND OATS AT DIFFERENT STAGES OF MATURITY[1]

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### INTRODUCTION

The advisability of harvesting grain crops previous to maturity under certain unfavorable environmental conditions has received considerable study. Many farmers of the northern border states have found it advisable to harvest their crops of wheat and oats in an immature stage because of impending frosts. Others have believed that during years of serious rust epidemics grain quality is lowered by permitting the crop to mature. Under certain conditions it would be advantageous to cut a part of the crop in an immature stage in order to care for large acreages within a reasonably short harvest period. It was with a view to securing data that might aid in solving these problems that the present investigations were undertaken.

In 1926, Arny and Sun (3)[3] reported the results of studies involving the effects of harvesting wheat and oats at different stages of maturity. The present paper deals with a continuation of these investigations. In 1927, however, rusts were prevalent to a marked degree. Marquis wheat was severely injured by leaf rust (*Puccinia triticina* Eriks.) and black stem rust (*P. graminis tritici* Eriks. and Henn.), while Victory oats was severely infected by crown rust (*P. coronata* Cda.) and stem rust (*P. graminis avenae* Eriks. and Henn.). The black stem rust infection on both crops was between 90 and 100%. It is believed that the rust attacks warrant the separate publication of the one year's results since rust was not a factor in previous years.

Extensive literature reviews are found in the general work of Arny (2) and later in the wheat and oat studies reported by Arny and Sun (3). Since the present studies are a continuation of those reported in the latter article, it is believed unnecessary to repeat an extensive review. Citations will be made in the body of the paper as occasion warrants.

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[3]Reference by number is to "Literature Cited," p. 1077.

## TECHNIC

In line with the preliminary work, Marquis wheat and Victory oats were seeded in 1/40 acre plats on May 2 at the rate of 90 and 64 pounds to the acre, respectively. Thirty plats of both wheat and oats provided ample material for a period of harvest extending over 10 days with the use of three plats daily. Since only 6 square yards were harvested from each plat for yield, it was possible to extend the harvest over a longer period if necessary. The prevalence of rusts delayed maturity and extended harvest over a longer period than was originally anticipated. As a result, the wheat harvest was started 13 days before maturity and the oat harvest 12 days.

*Sampling grain.*—Beginning with the first day of harvest, samples of grain were collected before sunrise each morning. Using a hand sickle, six to eight small bundles were harvested at random from different sections of each plat. As the plats were replicated, this gave a total of 18 to 24 small bundles which were placed in large canvas bags and taken immediately to the laboratory.

*Sample preparation.*—The small samples were carefully mixed and then sorted into about 20 lots of 50 average culms. The work was done rapidly to prevent drying of material before treatments were complete.

Since it seemed desirable to study the effect of different methods of drying harvested grain in relation to premature harvesting, samples were prepared to provide several methods of study. One bundle of 50 culms was divided into the following classes: (a) spikelets, (b) rachises, (c) first internodes, (d) first leaves, (e) second internodes, (f) second leaves, (g) remaining internodes, and (h) remaining leaves. A small sample from the spikelets was threshed by hand, removing the lemma and palea with the outer glumes. Green weights were taken on an enclosed torsion balance. After weighing, the eight groups were placed in a steam-heated oven with a temperature of about 90°C. Following preliminary drying, samples were dried to a constant weight in an electric oven at 105°C.

Other bundles of 50 culms each were prepared in eight different ways as follows: (a) full length of straw with leaves attached, (b) full length of straw with leaves removed, (c) two upper internodes with leaves attached, (d) two upper internodes with leaves removed, (e) upper internode with leaf attached, (f) upper internode with leaf removed, (g) spike or panicle, and (h) spikelets. Each lot was placed in a cotton bag and suspended under the eaves of a shed, providing protection from rainfall but permitting air circulation for rapid drying.

A third group was divided into 50-culm lots prepared in the following different manners: (a) full length with leaves attached, (b) two upper internodes with leaves attached, (c) first internode with leaf attached, (d) spike or panicle, and (e) spikelets. The spike or panicle and the spikelet lots were placed in cotton bags, while the other groups were tied in compact bundles. An additional bundle of full length culms with leaves attached was placed with the base in a quart jar of water. The six lots were placed in the field within shocks built with the grain which had been harvested with a binder following the removal of samples as explained below.

*Harvesting for yield.*—Early in the morning of each day areas of 6 square yards were removed for yield determination from each of three systematically distributed plats. The remainder of the plat was harvested with a binder. The six square-yard bundles and the samples prepared in the laboratory were placed within shocks on the respective plats. The grain was left in the shocks until sufficiently dry for threshing.

*Determinations.*—(a) Yield in bushels per acre was determined from an average of three systematically distributed plats. (b) Weight per bushel was determined by the methods outlined in the *Handbook of Official Grain Standards* for wheat, shelled corn, oats, and rye (4). (c) The percentage of dark, hard, and vitreous kernels of wheat was estimated by the method outlined in the *Handbook of Grain Standards*. (d) Thousand kernel weight was computed from duplicate lots of 250 kernels each which were weighed on an enclosed torsion balance. (e) Dry matter percentages were determined according to the usual methods. (f) Percentage of nitrogen was determined by the Kjeldahl method under the supervision of the Division of Agricultural Biochemistry. (g) Milling and baking tests were made under the supervision of the Division of Biochemistry. The threshed grain obtained from the plats, harvested on the various dates, was used and four loaves of bread were baked from grain obtained on each harvesting date. (h) Percentage of green wheat kernels was found by separation into groups of red and green colored lots and computing value of each. (i) Percentage of hulls in oats was determined by removing the lemmas and paleas of duplicated 250-kernel samples. (j) The rate of moisture loss was determined by the methods outlined by Livingstone (13). Atmometers were placed in a number of the wheat shocks and in the open air under the eaves of the shed.

## AGRONOMIC NOTES ON HARVEST DATES

It is often difficult for the reader to grasp the meaning of such phrases as early bloom, late bloom, etc. For this reason detailed plant notes were taken on each harvest date with a view of conveying a true picture of the stage of development to the reader.

### MARQUIS WHEAT

*Thirteen days early.*—Lower leaf blades mostly brown, with some green color on upper leaf blades. All leaf sheaths green except the lower. Terminal spikelet caryopsis in cream stage.

*Eleven days early.*—No noticeable change in appearance. First clear evidence of general rust infection.

*Nine days early.*—All leaf blades brown; upper leaf sheath green, second leaf sheath about one-third green. Terminal spikelet caryopses in thick cream to soft dough stage, others in cream stage. Considerable rust developing.

*Seven days early.*—Second leaf sheath brown, upper leaf sheath one-half brown. Outer glumes of upper spikelets faded green. Most of caryopses in soft dough stage.

*Five days early.*—Leaves entirely brown. Spikes faded green. Some caryopses of upper spikelets in hard dough stage.

*Four days early.*—Necks of culms yellow. A few spikes with all outer glumes white except for streaks of green color. All caryopses in soft to hard dough stage.

*Two days early.*—About one-half spikes with white outer glumes. Few terminal spikelet caryopses mature. Severe epidemic of stem rust apparent.

*One day early.*—Little change. About one-half upper spikelet caryopses mature.

*Mature.*—Very little green color on plant. Leaves quite dry. Most caryopses mature in all parts of spike.

### VICTORY OATS

*Twelve days early.*—Third leaf blade and tip of second brown. Third leaf sheath tinged with brown color. Terminal spikelet caryopses in thin cream stage, lower caryopses in milk stage.

*Ten days early.*—Tip of upper leaf blade brown. Third leaf sheath entirely brown. Glumes of terminal spikelets yellowing. Considerable variation in maturity. Much rust infection evident.

*Eight days early.*—Upper leaf blade one-half brown, sheath green. Few caryopses of terminal spikelets in soft dough stage, others in milk stage.

*Six days early.*—Most of the upper leaf blades brown. Terminal spikelet glumes white. Most of terminally borne caryopses in soft dough stage.

*Four days early.*—All leaf blades brown, upper sheath green, second sheath one-half brown. Terminal spikelet caryopses in hard dough stage; lower spikelets in soft dough stage.

*Two days early.*—All leaf parts brown. Most of outer glumes white, lower spikelets with some green color.

*One day early.*—Most outer glumes white. Terminal caryopses mature, others in hard dough stage.

*Mature.*—Plants brown. Most caryopses mature.

## EXPERIMENTAL RESULTS AND THEIR INTERPRETATION

One of the most noticeable effects of a severe epidemic of black stem rust is a slowing of the maturity rate of the crop. Although harvest was started when, according to past experience, it was thought that the grain should be mature within about 9 to 10 days, the plants failed to ripen until 12 to 13 days afterwards.

TABLE 1.—*Yield in bushels per acre, weight per bushel in pounds, dark, hard, and vitreous wheat kernels in per cent or percentage of oat hulls, and yield of straw in tons per acre of Marquis wheat and Victory oats harvested at indicated intervals.*

| Days to maturity when harvested | Grain in bushels per acre | Weight per bushel, pounds | Vitreous kernels or percentage hull, % | Grade, U. S. Standards | Tons of straw per acre |
|---|---|---|---|---|---|
| | | | Marquis Wheat | | |
| 13 | 12.7±0.56 | 39.8 | 65 | Sample Nor. Spring | 2.0 |
| 11 | 12.9±0.57 | 43.9 | 78 | Sample Dk. Nor. Spring | 2.3 |
| 9 | 13.3±0.59 | 45.4 | 84 | Sample Dk. Nor. Spring | 1.9 |
| 7 | 14.0±0.62 | 44.2 | 83 | Sample Dk. Nor. Spring | 1.8 |
| 5 | 11.8±0.52 | 44.8 | 77 | Sample Dk. Nor. Spring | 1.9 |
| 4 | 14.2±0.63 | 46.0 | 91 | Sample Dk. Nor. Spring | 1.9 |
| 2 | 16.6±0.74 | 46.3 | 90 | Sample Dk. Nor. Spring | 1.9 |
| 1 | 14.6±0.65 | 45.7 | 94 | Sample Dk. Nor. Spring | 1.8 |
| Mature | 14.8±0.66 | 48.0 | 91 | Sample Dk. Nor. Spring | 1.9 |
| | | | Victory Oats | | |
| 12 | 37.4±1.79 | 19.1 | 60 | Sample White | 1.5 |
| 10 | 40.9±1.96 | 20.6 | 52 | Sample White | 1.9 |
| 8 | 46.9±2.25 | 23.2 | 46 | No. 4 White | 1.8 |
| 6 | 46.4±2.22 | 25.0 | 44 | No. 4 White | 1.6 |
| 4 | 49.3±2.36 | 26.0 | 42 | No. 3 White | 1.7 |
| 2 | 45.4±2.17 | 26.3 | 39 | No. 3 White | 1.9 |
| 1 | 52.9±2.53 | 27.7 | 41 | No. 3 White | 1.7 |
| Mature | 52.9±2.53 | 26.4 | 36 | No. 3 White | 1.9 |

## YIELDS IN BUSHELS PER ACRE

Largely because of rust infection yields were low throughout the experiment. As shown in Table 1, grain yield increased as the plants approached maturity. While the yield of 16.6 bushels two days before maturity represents the highest yield of wheat, fluctuations were rather wide. Analyzed statistically, according to the probable error method as explained by Hayes and Garber (10), the decreased yields on the last two harvest dates are not significant. No shattering was observed and no loss is believed to have occurred in this manner. In an experiment at Davis, California, Reynoldson, *et al.* (16) found no shattering of Marquis wheat 10 days after maturity. Although conditions vary in different sections of the country, there is reason to believe that, in regard to shattering, Marquis would behave in a somewhat similar manner in Minnesota as compared with California. It appears probable that decreased yields were due to experimental error which was doubtless augmented by severe rust damage. In spite of fluctuations, it is evident that wheat yields increased until about four days before maturity.

As with spring wheat, Victory oat yields increased with approaching maturity (Table 1). In spite of a rather high experimental error, the yield increase from 37.4 bushels at the beginning of harvest to 52.9 bushels when mature was highly significant. Following the 10 days early harvest there was a gradual increase in yield to near maturity. Differences were not great enough to establish statistical significance. There can, however, be little question as to the truths illustrated by the rather uniform upward trend in yield. Increases of 12 to 15 bushels from the milk stage to maturity represent percentage increments of 29 to 41, respectively. The low yield two days before maturity is believed to be due to an error in determination, since it does not agree with the general trend of yields. The general upward trend of oat yields is more consistent than was the case with wheat.

## WEIGHT PER BUSHEL

Under normal growing conditions it is natural to expect the bushel weight to increase with approaching maturity. The lowest weight per bushel of wheat was 39.8 pounds on the initial harvest date. The samples harvested 5 to 11 days before maturity were of somewhat higher weight per bushel and the grain weight increased to a maximum of 48.0 pounds at maturity (Table 1). Since all spring wheat with a bushel weight below 50.0 pounds is Sample Grade under the U. S. Grain Standards (4), the increases did not change the numerical grade. There can be no question as to the superior value

of the heavier wheat. In a normal year when rust was not so severe, corresponding increases in weight would have exerted a marked influence on the numerical grade and market value. It is evident that black stem rust weakened the plants, interfered with normal functions, and led to the production of badly shriveled, low quality grain.

Ellis (6) harvested badly rusted wheat and found an increased yield with approach of maturity up to a stage when the grain was firm enough to resist pressure between the thumb and forefinger.

Stoa (21) also obtained the highest yields of wheat when the grain was permitted to mature.

Harrington (9), working with rusted common and durum wheat, concluded that rusted wheat should be harvested at the normal time in the same manner as for unrusted plants. He observed incomplete filling of kernels with greater subsequent shrinkage when the grain was harvested prematurely.

The effect of black stem rust and crown rust is evidenced by the low bushel weight of the oats (Table 1). There was an uniform increase in grain quality with approach of maturity. The weight increase of over 8 pounds per bushel is quite important in determining the value of the grain to be marketed. This increased weight raises the market grade from Sample to No. 3 (4).

## DARK, HARD, AND VITREOUS WHEAT KERNELS

Since the percentage of dark, hard, and vitreous kernels in a sample of hard red spring wheat is an important factor in determining the market subclass (4), it is important to note the effect of premature harvest on kernel characteristics. Except for minor fluctuations the percentage of vitreous kernels increased from 65 at the beginning of harvest to 94 one day before maturity (Table 1). There was no significant difference in the percentage of dark, hard, and vitreous kernels in grain harvested four days early, to and including maturity. As the U. S. Grain Standards set 75% vitreous kernels as a minimum for the highest subclass, Dark Northern Spring, the first grain harvested, fell in the next lower subclass, Northern Spring. Following the second harvest all samples graded Dark Northern Spring.

## PERCENTAGE OF HULL IN OATS

Since the flowering glumes remain attached to the caryopsis in threshing and are of little value for feeding purposes, it is desirable to decrease the oat hull percentage as much as possible. In general, the smaller the hull percentage, the greater the value of the oat for

feeding purposes. Except for one minor fluctuation, occurring just prior to maturity, there was a regular and pronounced decrease in hull percentage (Tables 1 and 2). As the hull is a part of the floral structure, it is formed early and remains rather constant in dry matter content except for slight transfer to the caryopsis. It is apparent that the hull percentage is determined by the extent of caryopsis development. The more favorable the condition for filling of the grain, the smaller is the percentage of hull. Varieties differ in thickness of hull, but working within a given variety increased hull is an indication of lowered grain quality.

TABLE 2.—*Average percentage hull of oats harvested on different dates and dried under different conditions.*

| Treatment | Days before maturity 12 | 10 | 8 | 6 | 4 | 2 | 1 | Mature | Average | Probable error of experiment % |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | In Bag Under Eaves of Shed | | | | | | |
| Full length, leaves attached | 69.4 | 48.7 | 48.1 | 45.5 | 41.1 | 42.2 | 38.8 | 39.9 | 46.7 | |
| Full length, leaves removed | 68.2 | 52.2 | 46.5 | 45.6 | 41.9 | 40.7 | 39.6 | 37.4 | 46.5 | |
| 2 upper internodes, leaves attached...... | 63.8 | 52.1 | 45.5 | 40.8 | 42.5 | 42.1 | 42.5 | 38.6 | 46.0 | |
| 2 upper internodes, leaves removed...... | 64.4 | 54.0 | 45.5 | 44.8 | 39.7 | 42.0 | 41.5 | 38.0 | 46.2 | |
| 1 upper internode, leaf attached...... | 66.6 | 52.0 | 44.2 | 45.7 | 41.6 | 42.5 | 42.2 | 38.6 | 46.7 | |
| 1 upper internode, leaf removed...... | 67.5 | 52.1 | 43.9 | 47.7 | 43.4 | 41.0 | 42.3 | 40.7 | 47.3 | |
| Panicle only... | 72.6 | 56.7 | 47.5 | 45.5 | 42.7 | 38.7 | 42.6 | 41.4 | 48.5 | |
| Spikelets only. | 68.4 | 54.2 | 48.5 | 41.3 | 41.3 | 40.9 | 43.8 | 40.6 | 47.4 | |
| Average...... | 67.6 | 52.8 | 46.2 | 44.6 | 41.8 | 41.3 | 41.7 | 39.4 | 46.9 | 0.93 |
| | | | | In Shock | | | | | | |
| Full length.... | 60.0 | 51.5 | 45.7 | 43.6 | 42.0 | 38.5 | 40.8 | 36.2 | 44.8 | |
| 2 upper internodes........ | 61.7 | 61.1 | 44.4 | 41.3 | 40.6 | 41.5 | 38.7 | 38.4 | 45.9 | |
| 1 upper internode......... | 69.6 | 47.2 | 44.1 | 42.3 | 40.7 | 40.0 | 38.1 | 36.9 | 44.9 | |
| Panicle only... | 67.3 | 64.7 | 43.9 | 40.5 | 41.8 | 37.9 | 38.4 | 38.9 | 46.7 | |
| Spikelets only. | 69.3 | 53.0 | 46.9 | 43.6 | 41.3 | 40.6 | 38.9 | 39.4 | 46.6 | |
| Average...... | 65.6 | 55.5 | 45.0 | 42.3 | 41.3 | 39.7 | 38.9 | 38.0 | 45.8 | 1.01 |
| | | | | In Shock, Culm Bases in Water | | | | | | |
| Full length.... | 60.3 | 48.9 | 45.9 | 43.0 | 43.6 | 39.3 | 41.7 | 39.6 | 45.3 | 1.52 |

On an average, hull percentages decreased from the earliest harvested grain to the stage of maturity. The grain from plants dried in the shed decreased in hull percentage from 68 to 39, in the shock from 66 to 38, and with stems in water from 60 to 40.

### YIELD OF STRAW PER ACRE

Wheat straw yields were highest at the beginning of harvest and decreased with accompanying increased grain development as ripening progressed (Table 1). The translocation of temporarily stored materials from the straw to the developing caryopsis is largely responsible for decreased straw yields as this is a well-known physiological action. While straw yields were somewhat variable, they indicate a downward trend in production. Shattering of dried leaf blades was an additional factor in reducing the amount of straw. During the first harvests, the loss was small, increasing with succeeding harvests as the plants dried, with considerable fluctuation probably due to experimental error.

Shutt (19) found the straw from rusted wheat to be richer in crude protein and fat with somewhat less fiber than was present in rust-free straw. He believed these differences were a result of the fungus interfering with normal movement of materials to the grain of the rust-infected plants.

Yield of oat straw in tons per acre did not change greatly from the harvest 10 days early to maturity (Table 1). Straw production fluctuated but did not show any consistent change. It should be recognized that tons per acre represent units which are rather large to illustrate clearly slight changes which are probably due to translocation of food reserves.

### THOUSAND KERNEL WEIGHT.

Grain harvested from differently treated culms, as indicated in an earlier part of this paper, were studied on the basis of possible differences in weight of 1,000 kernels. In wheat the naked caryopsis was used, while in oats the caryopsis and the two flowering glumes were considered as a kernel.

Weight in grams per 1,000 kernels of wheat increased with the approach of maturity (Table 3). Increases were rapid during the first eight days of the experiment, then followed a gradual upward trend with minor fluctuations from day to day. These fluctuations were small and, when analyzed statistically, are of little significance. The increase from an average of 9.93 grams per 1,000 kernels from plants harvested in the milk stage, and dried in the shock, to 17.21 grams at maturity represents an increment of more than 70%. As

TABLE 3.—*Oven-dry weight of 1,000 wheat kernels harvested on different dates and dried under the conditions indicated.*

| Treatment | Days before maturity 13 | 11 | 9 | 7 | 5 | 4 | 2 | 1 | Maturity | Average | Probable error of experiment, % |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | In Bag Under Eaves of Shed | | | | | | |
| Full length, leaves attached... | 13.5 | 12.6 | 13.6 | 15.2 | 15.7 | 16.8 | 16.8 | 16.5 | 16.9 | 15.3 | |
| Full length, leaves removed... | 13.1 | 12.8 | 15.0 | 15.3 | 15.9 | 17.7 | 17.5 | 17.9 | 17.7 | 15.9 | |
| 2 upper internodes, leaves attached... | 12.1 | 12.9 | 14.3 | 14.6 | 16.2 | 15.7 | 16.3 | 16.9 | 17.3 | 15.1 | |
| 2 upper internodes, leaves removed... | 12.3 | 12.7 | 14.9 | 15.4 | 16.7 | 15.8 | 17.8 | 17.4 | 16.9 | 15.5 | |
| 1 upper internode, leaf attached... | 12.5 | 13.2 | 15.1 | 14.8 | 16.6 | 16.2 | 17.0 | 17.2 | 18.1 | 15.6 | |
| 1 upper internode, leaf removed... | 11.8 | 12.9 | 15.4 | 15.3 | 15.9 | 15.7 | 16.6 | 16.4 | 17.5 | 15.3 | |
| Rachis only | 12.4 | 13.0 | 14.4 | 14.8 | 16.6 | 15.5 | 18.2 | 16.6 | 16.9 | 15.4 | |
| Spikelets only...... | 11.9 | 13.3 | 14.4 | 15.9 | 16.6 | 15.9 | 16.2 | 17.7 | 16.0 | 15.3 | |
| Average... | 12.5 | 12.9 | 14.6 | 15.2 | 16.3 | 16.2 | 17.1 | 17.1 | 17.2 | 15.4 | 0.99 |
| | | | | | In Shock | | | | | | |
| Full length. | 9.6 | 11.9 | 14.0 | 14.3 | 16.4 | 15.5 | 16.9 | 16.6 | 17.2 | 14.7 | |
| 2 upper internodes..... | 10.1 | 10.6 | 13.4 | 14.7 | 15.6 | 16.7 | 15.9 | 15.1 | 17.5 | 14.4 | |
| 1 upper internode...... | 10.9 | 11.4 | 12.6 | 14.9 | 16.6 | 15.6 | 15.6 | 16.3 | 16.9 | 14.6 | |
| Rachis only. | 9.1 | 12.3 | 12.8 | 14.7 | 15.9 | 15.1 | 15.6 | 16.4 | 17.2 | 14.3 | |
| Spikelets only...... | 9.8 | 12.9 | 13.2 | 15.2 | 15.3 | 15.0 | 17.0 | 17.2 | 17.2 | 14.8 | |
| Average.... | 9.9 | 11.8 | 13.2 | 14.8 | 15.9 | 15.6 | 16.2 | 16.3 | 17.2 | 14.5 | 0.95 |
| | | | | | In Shock, Culm Bases in Water | | | | | | |
| Full length. | 11.6 | 13.8 | 14.3 | 13.4 | 15.8 | 14.9 | 18.6 | 19.3 | 18.9 | 15.6 | 2.23 |
| | | | | | Dried in Oven Immediately | | | | | | |
| Full length. | 12.0 | 13.6 | 13.6 | 15.0 | 16.0 | 17.4 | 17.1 | 18.6 | 19.0 | 15.8 | not determined |

measured by the probable error of the difference of these values, the odds are great that this increase was not due to chance fluctuation. Similar, although not so marked, increases occurred with plants

dried in bags suspended in the air, full length plants with stems in water, and plants dried in an oven immediately following harvest.

The movement of storage materials, chiefly carbohydrates, into the wheat kernel is rapid from the milk stage to near maturity, as has been noted by McDowell (14), Thatcher (22), Saunders (17), Shutt (19), Olson (15), Kiesselbach (11), Arny and Sun (3), and others.

Failyer and Willard (7) were among the earliest workers to note an increased 1,000-kernel weight for mature wheat as compared with grain harvested in the soft dough stage.

Saunders (18), in a recent study of the wheat kernel development, reported daily increases in 1,000-kernel weight up to the last two days preceding maturity, after which there was a slight loss.

It is interesting to note that the plants dried immediately in the oven after harvest yielded consistently heavy grain throughout the harvest period. This indicates that any possible increments in kernel weight due to the transfer of food materials from straw to grain which may have occurred following cutting of the plants which were dried slowly were too small to be measured by the technic of this experiment. There was little or no opportunity for a transfer of stored reserves in the oven-dried grain, since it was subjected to a temperature of approximately 90°C. Full-length plants with the basal portions of their culms immersed in water yielded grain of greater weight than the average for plants cured in the shock. The average kernel weights, however, were less than for grain placed in the oven. This evidence renders it unlikely that water was in any manner effective in promoting increased kernel development. Harlan and Pope (8) found the barley caryopsis to increase through a period of eight days after sampling provided the culm was kept moist. However, their studies involved a much earlier stage of plant development as they worked with plants during the time of fertilization and immediately following.

The grain from plants dried under the eaves of a shed showed a similar trend in kernel weight as that from the other groups.

Considering the different plant portions and their respective kernel weights, it is evident that no significant differences existed. Grain from full-length plants, with leaves attached, harvested 13 days early and dried under the shed gave the greatest kernel weight of any group. Two days later the reverse was true when full-length plants with leaves attached yielded grain with the lowest 1,000-kernel weight. Group averages should be more reliable than individual weights and these show no significant differences. Odds of statistical significance are less than 20 to 1 for the greatest average

1,000-kernel weight difference, that between grain from culms in which one upper internode with leaf removed and grain from the full length of plant with all leaves removed. The 1,000-kernel weights of grain from different plant sections dried in the shock fluctuated similarly to those from plants dried under the shed.

These data indicate that transfer of food material to the wheat kernel following harvest, if any, was too small to be measured in increased 1,000-kernel weight. It appears that appreciable translocation of reserves from the vegetative portions of the plant to the caryopsis ends with severance from the root. This is indicated for plants from the milk stage to maturity.

Since all harvested plants were removed from the light, and the water content fell rapidly, photosynthesis stopped shortly after harvest. Any photosynthetic products not moved immediately to various parts of the plant are deposited as reserves, principally starches. Before these materials can be translocated they must again go into solution. This requires an abundance of water which would not be present long after harvest. This helps to explain why there were no evident increases in kernel weight following harvest.

Olson (15) states that wheat does not fill after the moisture content has dropped to 40%. He also noted that gluten formation in the wheat kernel was slowed when the moisture content was reduced from 65 to 59%. It is evident from the data in Table 5 that the water content was near, or would soon reach, the critical points suggested by Olson as limiting translocation.

The weight per 1,000 kernels (caryopses with adhering flowering glumes) of oats was similar to the results obtained with wheat. Under each of the methods to which the harvested plants were subjected, the 1,000-kernel weight increased from the milk stage to maturity (Table 4). Full length plants placed with culm bases in water after harvest show a somewhat higher kernel weight for the first two harvest periods than the averages for corresponding dates when the grain was hung under the shed eaves and when contrasted with that shocked in the ordinary manner. These increases are believed to be due to random sampling, since some of the plant groups dried in the shock and in the shed yielded grain with as great or greater kernel weight on the corresponding dates.

There were no conclusive differences between the kernel weight of grain as affected by attachment to different plant portions. It appears that the oat results corroborate those given for wheat.

TABLE 4.—*Oven-dry weight of 1,000 oat kernels harvested on different dates and dried under indicated conditions.*[a]

| Treatment | Days before maturity 12 | 10 | 8 | 6 | 4 | 2 | 1 | Mature | Average | Probable error of experiment, % |
|---|---|---|---|---|---|---|---|---|---|---|
| In Bag Under Eaves of Shed | | | | | | | | | | |
| Full length, leaves attached | 15.6 | 13.4 | 14.4 | 14.7 | 17.6 | 16.6 | 18.8 | 18.9 | 16.3 | |
| Full length, leaves removed | 12.0 | 11.9 | 15.0 | 16.4 | 16.4 | 17.8 | 18.2 | 18.4 | 15.7 | |
| 2 upper internodes, leaves attached | 12.1 | 12.3 | 14.0 | 16.9 | 17.2 | 16.1 | 17.1 | 18.2 | 15.5 | |
| 2 upper internodes, leaves removed | 12.0 | 12.0 | 15.2 | 16.6 | 18.1 | 16.8 | 16.8 | 17.6 | 15.6 | |
| 1 upper internode, leaf attached | 12.9 | 13.3 | 14.7 | 15.7 | 15.0 | 15.9 | 17.0 | 18.4 | 15.4 | |
| 1 upper internode, leaf removed | 15.9 | 13.1 | 15.7 | 15.5 | 16.4 | 16.9 | 16.8 | 17.7 | 16.0 | |
| Panicle only | 11.4 | 12.1 | 13.7 | 16.2 | 16.7 | 18.0 | 16.7 | 17.5 | 15.3 | |
| Spikelets only | 11.8 | 13.6 | 14.0 | 18.4 | 18.0 | 18.0 | 17.0 | 18.0 | 16.1 | |
| Average | 13.0 | 12.7 | 14.6 | 16.3 | 16.9 | 17.0 | 17.3 | 18.1 | 15.7 | 1.47 |
| In Shock | | | | | | | | | | |
| Full length | 12.4 | 13.6 | 15.0 | 15.1 | 15.8 | 17.9 | 16.8 | 17.8 | 15.5 | |
| 2 upper internodes | 11.9 | 12.2 | 14.4 | 16.3 | 18.5 | 17.0 | 18.2 | 17.6 | 15.8 | |
| 1 upper internode | 15.0 | 14.9 | 15.0 | 15.4 | 17.2 | 16.7 | 17.5 | 18.4 | 16.3 | |
| Panicles only | 11.5 | 15.4 | 15.2 | 17.9 | 16.2 | 18.7 | 18.7 | 17.9 | 16.4 | |
| Spikelets only | 15.8 | 13.8 | 14.4 | 15.4 | 16.8 | 17.6 | 17.9 | 16.8 | 16.1 | |
| Average | 13.3 | 14.0 | 14.8 | 16.0 | 16.9 | 17.6 | 17.8 | 17.7 | 16.0 | 1.49 |
| In Shock, Culm Bases in Water | | | | | | | | | | |
| Full length, leaves attached | 15.9 | 15.0 | 14.8 | 15.8 | 14.9 | 17.2 | 16.0 | 17.6 | 15.9 | 1.46 |

### PERCENTAGE OF DRY MATTER

When the wheat caryopses were in the milk stage, 13 days before maturity, all parts of the plant contained considerable water with corresponding low percentages of dry matter (Table 5). It is commonly understood that in grass plant senescence, the lower leaves are first to suffer because of their greater age. With death, water is lost and dry matter percentage increases. The caryopsis, internodes, and upper leaves were lowest in dry matter percentage at the beginning of harvest. Had the harvest been started earlier, there probably would have been a stage when the dry matter of the lowest leaves was equal to that of the upper.

Loss of water with accompanying increase of percentage dry matter was rapid with approach of maturity. It is evident that the increased dry matter percentages of the vegetative plant portions,

TABLE 5.—*Percentage dry matter of different parts of wheat and oat plants harvested at periodic stages of development.*

| Days before maturity | Kernels and glumes | Caryopses | Glumes | Rachises | Top internodes | Top leaves | Second internodes | Second leaves | Remaining internodes | Remaining leaves |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Marquis Wheat | | | | | |
| 13 | 38.2 | 36.8 | 47.6 | 43.7 | 48.8 | 44.9 | 35.9 | 55.7 | 35.2 | 66.1 |
| 11 | 42.2 | 42.6 | 56.3 | 46.5 | 44.1 | 50.9 | 36.9 | 54.5 | 36.3 | 71.4 |
| 9 | 46.2 | 44.2 | 58.5 | 53.3 | 47.7 | 62.5 | 43.5 | 70.5 | 45.4 | 79.9 |
| 7 | 49.2 | 50.3 | 59.6 | 52.5 | 51.9 | 61.7 | 44.0 | 69.2 | 48.0 | 83.0 |
| 5 | 51.6 | 51.8 | 58.2 | 54.5 | 51.1 | 61.9 | 44.5 | 72.5 | 48.4 | 81.8 |
| 4 | 56.5 | 55.7 | 74.4 | 60.7 | 57.6 | 71.6 | 52.9 | 84.5 | 56.4 | 88.7 |
| 2 | 60.1 | 60.6 | 75.9 | 63.7 | 59.3 | 77.7 | 56.4 | 87.5 | 61.3 | 91.0 |
| 1 | 64.3 | 61.4 | 73.6 | 68.4 | 61.9 | 83.3 | 59.2 | 89.1 | 61.2 | 90.6 |
| Mature | 68.8 | 69.3 | 85.9 | 66.9 | 61.2 | 81.2 | 61.6 | 87.9 | 66.3 | 90.3 |
| | | | | | Victory Oats | | | | | |
| 12 | 39.5 | 30.3 | 56.8 | 42.5 | 27.8 | 29.4 | 23.1 | 24.5 | 24.5 | 26.1 |
| 10 | 43.4 | 41.3 | 58.6 | 43.3 | 30.0 | 29.2 | 26.7 | 28.5 | 27.2 | 39.5 |
| 8 | 45.9 | 46.6 | 53.9 | 42.4 | 29.1 | 28.9 | 27.4 | 30.1 | 28.5 | 41.3 |
| 6 | 51.9 | 55.2 | 63.6 | 44.9 | 32.8 | 35.9 | 31.3 | 44.9 | 32.5 | 58.9 |
| 4 | 56.3 | 59.1 | 64.8 | 45.6 | 33.9 | 38.6 | 33.6 | 49.9 | 35.5 | 61.1 |
| 2 | 66.8 | 69.9 | 75.6 | 50.4 | 43.5 | 55.3 | 43.1 | 66.8 | 44.5 | 75.6 |
| 1 | 74.8 | 75.2 | 76.8 | 58.9 | 51.8 | 77.9 | 51.8 | 77.8 | 51.9 | 80.9 |
| Mature | 81.3 | 85.8 | 90.3 | 70.2 | 58.4 | 70.4 | 58.1 | 74.9 | 55.9 | 83.9 |

TABLE 6.—*Total grams of dry matter from different parts of 50 wheat and 50 oat plants harvested at periodic stages of development.*

| Days before maturity | Kernels and glumes | Caryopses | Glumes | Rachises | Top internodes | Top leaves | Second internodes | Second leaves | Remaining internodes | Remaining leaves |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Marquis Wheat | | | | | |
| 13 | 22.53 | 1.56 | 1.00 | 1.74 | 8.81 | 9.42 | 8.14 | 5.98 | 9.65 | 4.87 |
| 11 | 22.08 | 1.65 | 0.90 | 1.79 | 8.12 | 8.57 | 7.26 | 5.60 | 6.90 | 3.60 |
| 9 | 25.73 | 1.21 | 0.72 | 1.84 | 8.39 | 8.81 | 7.77 | 5.96 | 5.91 | 2.55 |
| 7 | 26.32 | 1.73 | 0.88 | 1.79 | 8.25 | 9.10 | 7.04 | 5.90 | 7.81 | 4.65 |
| 5 | 27.33 | 1.83 | 0.92 | 1.70 | 7.93 | 8.84 | 7.23 | 5.92 | 6.18 | 2.88 |
| 4 | 28.04 | 2.09 | 0.90 | 2.02 | 8.26 | 9.73 | 6.99 | 5.83 | 6.09 | 2.66 |
| 2 | 29.22 | 2.15 | 0.98 | 2.07 | 8.31 | 9.51 | 7.11 | 5.81 | 6.33 | 3.04 |
| 1 | 27.34 | 2.16 | 0.95 | 2.03 | 8.08 | 9.00 | 6.78 | 5.97 | 7.69 | 3.46 |
| Mature | 32.84 | 2.40 | 1.04 | 2.15 | 9.36 | 9.94 | 7.85 | 6.32 | 8.24 | 3.82 |
| | | | | | Victory Oats | | | | | |
| 12 | 49.20 | 0.71 | 1.29 | 5.06 | 15.29 | 15.20 | 12.05 | 15.73 | 10.73 | 11.94 |
| 10 | 55.66 | 0.84 | 1.33 | 5.21 | 14.65 | 18.01 | 11.78 | 16.87 | 16.10 | 16.05 |
| 8 | 60.09 | 1.16 | 1.25 | 4.81 | 14.08 | 16.34 | 11.50 | 15.28 | 10.97 | 12.06 |
| 6 | 70.23 | 1.37 | 1.26 | 5.49 | 15.91 | 18.90 | 12.15 | 15.64 | 10.84 | 10.33 |
| 4 | 74.85 | 1.40 | 1.27 | 5.20 | 15.82 | 18.11 | 12.20 | 15.16 | 10.92 | 9.19 |
| 2 | 74.86 | 1.90 | 1.80 | 5.29 | 15.93 | 19.03 | 11.58 | 14.50 | 8.57 | 6.70 |
| 1 | 63.90 | 2.00 | 1.62 | 4.59 | 13.78 | 16.84 | 10.14 | 14.18 | 8.79 | 8.55 |
| Mature | 75.63 | 2.12 | 2.04 | 5.11 | 13.89 | 17.50 | 10.39 | 15.13 | 10.08 | 9.45 |

with the exception of the glumes, were largely a direct result of water loss with maturity. The total grams of dry matter produced by the different parts of 50 plants, as given in Table 6, verify the preceding statement. Losses were greatest in the lower leaves, due largely, no doubt, to loss from shattering.

All parts of the oat plant showed increased dry matter percentages with approaching maturity. This is similar to the results for wheat, although it is interesting to observe that the water content of the oat plant tended to average considerably higher from milk stage to maturity than was true of wheat. With small fluctuations, the actual dry matter in the glumes and grain increased with successive harvests. As with wheat, the other portions of the plant remained more or less constant, showing again that the principal change in the vegetative portions was loss of water with senescence.

These data indicate that when the plant is nearing maturity food materials are moved from the leaf of the plant largely as formed or shortly afterwards. With chlorophyll disintegration, as evidenced by loss of green color, there follows a marked reduction in photosynthesis as indicated by lessened kernel development.

## PERCENTAGE OF NITROGEN

Since nitrogen is laid down early in the kernel development, as has been observed by Liebscher (12), Snyder (20), Adorjan (1), and others, it is natural to expect the percentage in grain to decrease with approaching maturity and accompanying inflow of carbohydrates. The data in Table 7 indicate a slight reduction in percentage of nitrogen in the wheat caryopses. The glumes and rachises showed considerable reduction in percentage from the beginning of harvest to maturity. Differences were small in many cases. The upper and lower internodes increased in nitrogen percentage, prob-

TABLE 7.—*Percentage nitrogen in different parts of wheat and oat plants harvested at different stages of development.*

| | Marquis wheat | | | Victory oats | | |
|---|---|---|---|---|---|---|
| | 13 days | 7 days | Mature | 12 days | 6 days | Mature |
| Caryopses | 2.09 | 2.08 | 2.05 | 2.91 | 2.18 | 2.47 |
| Glumes | 1.20 | 1.17 | 0.78 | 1.19 | 0.95 | 1.00 |
| Rachises | 1.00 | 0.89 | 0.73 | 1.24 | 0.98 | 0.87 |
| First leaves | 1.08 | 1.02 | 1.02 | 0.68 | 0.81 | 0.85 |
| Second leaves | 1.87 | 1.84 | 1.85 | 1.60 | 1.54 | 1.63 |
| Remaining leaves | 0.55 | 0.58 | 0.67 | 0.47 | 0.47 | 0.41 |
| First internode | 1.34 | 1.39 | 1.57 | 1.45 | 1.43 | 1.64 |
| Second internodes | 0.35 | 0.31 | 0.33 | 0.41 | 0.38 | 0.32 |
| Remaining internodes | 1.05 | 1.12 | 1.31 | 1.14 | 1.33 | 1.42 |

ably due to a movement of carbohydrates to the seed and a change in the nitrogen-carbohydrate ratio.

Data in Table 7 indicate a slightly higher percentage of protein in grain harvested early. However, this is more than offset by the reduced yields of grain and the shriveled, low grade kernels. Harvesting wheat a few days before maturity is not likely to change the actual amount of nitrogen greatly, since most of the nitrogen enters into the formation of the seed structure. Changes following this period are principally the deposition of carbohydrates and fats within the caryopsis skeleton, and this in turn affects the proportion of nitrogen present.

Nitrogen results with oats are similar to those obtained for wheat. The limited number of determinations show a decreased nitrogen percentage in the grain, glumes, and rachis with approaching maturity. The percentage in the leaves remained nearly constant during ripening, while the internodes, except the second, increased in nitrogen. This increase was probably the result of change of balance between carbohydrates and protein, as previously suggested. No explanation is given for the decreased nitrogen percentage of the second internode.

## MILLING AND BAKING TESTS

The results of milling and baking studies are given in Table 8. On the whole, the data indicate the superiority of the grain from the later harvests. Total flour increased to a maximum just before maturity, while the crude protein percentage was somewhat variable, being nearly the same for grain harvested 11 days early as for that

TABLE 8.—*Results of milling and baking tests of Marquis wheat harvested at different stages of maturity.*

| Time of harvest, days before maturity | Total flour % | Crude protein (N×5.7) % | Average absorption | Loaf Volume, cc | Loaf Color* | Loaf Grain | Loaf Texture |
|---|---|---|---|---|---|---|---|
| 13 | 60.2 | 12.41 | 58 | 460 | 96.7y | 96.7 | 97.3 |
| 11 | 61.0 | 13.18 | 60 | 444 | 96.5y | 96.7 | 98.7 |
| 9 | 61.2 | 12.29 | 54 | 426 | 96.7y | 97.2 | 98.7 |
| 7 | 61.2 | 12.54 | 57 | 443 | 96.8y | 97.1 | 98.7 |
| 5 | 62.0 | 12.05 | 53 | 466 | 97.3y | 98.2 | 99.1 |
| 4 | 61.0 | 12.15 | 55 | 431 | 98.0y | 99.1 | 99.0 |
| 2 | 60.5 | 12.28 | 54 | 418 | 98.2y | 99.3 | 98.6 |
| 1 | 62.5 | 12.14 | 52 | 430 | 98.8cy | 99.2 | 99.3 |
| Mature | 62.5 | 13.11 | 52 | 433 | 98.7cy | 99.1 | 99.0 |

*y = yellow, cy = creamy yellow.

permitted to mature. Water absorption percentages and loaf volume decreased with approach of maturity. Loaves of bread from the earliest harvest were decidedly yellow in color with poor grain and texture. The improvement in loaf quality was rather uniform with successive harvests, reaching a maximum for loaf color and texture one day before maturity. These results indicate an advantage in certain milling and baking qualities for the more nearly mature grain. The somewhat large loaf volume of the bread baked from the earliest harvest was offset by the poor texture and yellow color.

The grain was not subjected to unfavorable weather conditions as a result of remaining in the field until mature. Grain discoloration due to alternate wetting and drying had no effect upon the baking qualities of Kanred wheat in an experiment conducted by Bracken and Bailey (5). Some claims have been made for premature harvest on the basis of thus being able to obtain better quality grain for milling and baking.

## PERCENTAGE OF GREEN CARYOPSES OF WHEAT

Grain removed from the flowering glumes immediately upon harvest seven days before maturity and dried in the oven yielded 100% green colored kernels following drying (Table 9). Unthreshed grain harvested upon the same date but dried within the shock showed only 14% green color. Grain from wheat harvested seven days before maturity and dried in the shock had lost all green color, while the caryopses harvested on the same date and dried in the oven were 95% green after drying. Of grain dried in the oven, all green color did not disappear until maturity. The differences in color are

TABLE 9.—*Percentage of green caryopses in Marquis wheat for different maturity stages dried in oven and in shock.*

| Days before maturity | Oven | Shock |
|---|---|---|
| | % | % |
| 13 | 100.0 | 14.0 |
| 11 | 100.0 | 4.0 |
| 9 | 100.0 | 2.0 |
| 7 | 100.0 | 0.0 |
| 5 | 91.0 | 0.0 |
| 4 | 85.0 | 0.0 |
| 2 | 21.0 | 0.0 |
| 1 | 5.0 | 0.0 |
| Mature | 0.0 | 0.0 |

probably due to life action being stopped immediately in the oven and this in turn prevented the oxidation of the green chlorophyll pigments which mask the red and yellow constituents of the caryopsis.

### PERCENTAGE OF OAT CHAFF

Spikelets from grain which had been dried in the oven were carefully threshed and the weights of glumes recorded. It is interesting to note that the chaff, as represented by the glumes, decreased from 40% at the beginning of harvest to 31% at maturity. This reduction in chaff percentage parallels the increased 1,000-kernel weight referred to in an earlier part of this paper.

### LENGTH OF INTERNODES

In order to learn of possible changes, if any, occurring in plant length from the milk stage to maturity, detailed measurements were taken of the first and second internodes (Table 10). Fifty culms were used for each average. It is evident that internode length remained constant throughout the period of harvest, since differences are too small to have any appreciable mathematical significance.

TABLE 10.—*Average internode length in centimeters of Marquis wheat and Victory oats.*

| | Wheat | | | Oats | |
|---|---|---|---|---|---|
| Days before maturity | First internode | Second internode | Days before maturity | First internode | Second internode |
| 13 | 40 | 21 | 12 | 42 | 20 |
| 11 | 40 | 21 | 10 | 43 | 21 |
| 9 | 40 | 22 | 8 | 42 | 20 |
| 7 | 39 | 21 | 6 | 44 | 21 |
| 5 | 39 | 21 | 4 | 44 | 20 |
| 4 | 39 | 20 | 2 | 43 | 20 |
| 2 | 38 | 20 | 1 | 41 | 19 |
| 1 | 39 | 20 | Mature | 39 | 18 |
| Mature | 40 | 21 | | | |

### ATMOMETER RESULTS

Only a limited number of atmometers were available and the results merely serve as an indication of the relative drying conditions. As the atmometer determines the evaporation of water, it is a measure of the dryness of the air. This in turn is an index as to the relative drying rate of grain in shock. The lower the amount of water given off by the atmometer the greater was the amount of moisture in its immediate environment. The results for two successive dates of harvest are given in Fig. 1. The line labeled "open air shaded" was a measure of normal atmospheric conditions for the successive dates.

It is interesting to note the greater water loss of the more mature grain and the ultimate equilibrium reached between the air within the shocks and the atmosphere.

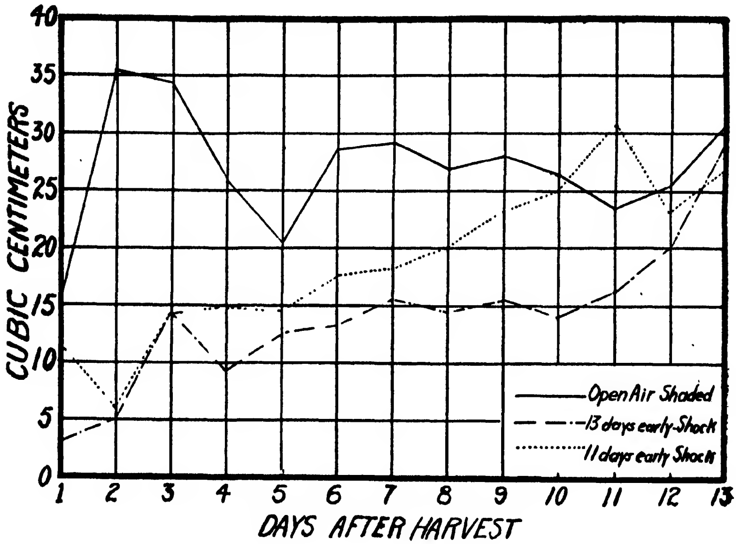


FIG. 1.—Loss of water in cc as measured by Livingstone's atmometers placed within shocks and in shaded atmosphere.

SUMMARY


1. There appeared to be no advantages from premature harvesting of rust-infected wheat or oats. The yield of Marquis wheat and Victory oats increased from the time the grain was in the milk stage until shortly before maturity. Kernel development failed only when senescence had set in with resulting disintegration of chlorophyll and tissue dessication.

2. Grain quality, as measured by increased weight per bushel and 1,000-kernel weight, was greater when plants were permitted to mature before harvest. Premature cutting, until about six days before maturity, resulted in lowered grain weight in both wheat and oats.

3. The grade of wheat was not increased with approach of maturity, even though the percentage of dark, hard, and vitreous kernels increased to a point near maturity. The bushel weight of both wheat and oats was low enough to cause all grain to be designated as "Sample Grade."

4. No recognizable differences in 1,000-kernel weight were noted for grain from plants dried in the oven immediately upon harvest, dried in shock in regular manner, in shock with culm bases in water, and in bags under the eaves of a building.

5. There were no differences in 1,000-kernel weight of grains attached to the full-length plant as contrasted with seed from severed spikelets.

6. Apparently, transfer of material from the plant to the seed after harvest was too small to appear in increased kernel weight. Both wheat and oats gave increased percentages of dry matter with maturity. With the exception of glumes and grain, this was largely the result of water loss. In glumes and grain the actual dry matter increased.

7. Nitrogen percentage of both wheat and oats decreased slightly with maturity.

8. Nearly mature to mature wheat was decidedly superior in milling and baking value. This was especially true of loaf color.

9. In both crops, straw yields tended to decrease, while grain yields increased as the plants matured.

10. Life action probably continues for some time after harvest as evidenced by the wheat caryopses changing from green to red when left within the glumes but remaining green when dried in an oven.

11. There were no changes in internodal length from the milk stage to maturity.

12. Evaporation of water from plants as measured by the atmometer was greater in shocks built from more mature plants.

13. The percentage of oat hull (lemma and palea) decreased with kernel development during successive harvests.

14. On the basis of these and earlier results (3), there appears to be no more justification for premature harvest during rust epidemics than during years when no epidemic is present.

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# KUDZU PRODUCTION WITH SPECIAL REFERENCE TO INFLUENCE OF FREQUENCY OF CUTTING ON YIELDS AND FORMATION OF ROOT RESERVES[1]

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One of the promising perennial hay and forage crops for the southern states in kudzu, a leguminous vine native to Japan. Its culture seems especially well suited to poor or rough, uncultivated soils where a perennial hay crop is desired, since it grows rapidly even on poor soils. Due to its rather recent introduction in to this country, many questions regarding its culture remain to be answered. Some of the most important questions are the best methods for securing a stand and the frequency and time of cutting as affecting yields and permanency of stand.

Observations made during the past ten or more years at the Alabama Agricultural Experiment Station indicated that heavy grazing or frequent and late cuttings may be detrimental to both stand and yield. These questions were believed to be related to the reserve food storage in the roots, for such correlations between frequency of cutting, yields, and the storage materials in the roots of other perennial crops have been obtained in recent years by various investigators. Investigators at the Wisconsin (1, 3, 5),[3] Missouri (8, 9), and Kansas (7) experiment stations have done some outstanding work in this respect. It is not the purpose of the writers to review the literature here, for good reviews have been made by Leukel (3), Albert (1), and Salmon, *et al.* (7).

The purposes of this investigation were as follows: (a) To determine the effect of the number of cutting treatments on the yield of tops and the size and composition of the roots of kudzu; (b) to study the formation of reserve carbohydrates and nitrogen in the roots during the growing season, and the effects of late cuttings on this reserve; and (c) to determine the effect of planting roots containing various amounts of storage material on the percentage of such plants that live and on the rapidity of new growth.

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[3]Reference by number is to "Literature Cited," p. 1101.

## GENERAL PROCEDURE AND METHODS

A preliminary greenhouse experiment with plants in 4-gallon pots was started in 1925. The following spring the field work was started. The plants were grown on a rather poor, unfertilized, Norfolk loamy sand on the station farm. Since kudzu seeds do not germinate well, the plants were started by transplanting well-rooted plants or, as in the case of Experiment I, by the rooting of vines at the nodes. Care was taken that the roots planted were not injured and that they were not allowed to dry before planting. Holes in the soil were made with a post-hole digger and the roots were placed perpendicular with their crowns and covered with soil.

In studying the effect of frequent cutting treatments on root storage, the cutting treatments were not started until the second year, thus allowing the plants to become established. Records of yields were kept on each individual plant throughout the season. In doing this it was necessary to keep the vines from entangling with one another. It was also necessary to prevent the vines from rooting at the nodes, since the storage in the original root could be studied only in this manner. At the end of each growing season some of the roots were dug in order to study their growth during the season or their composition of reserve food material. They were immediately brought to the laboratory in wet burlap sacks, washed thoroughly, dried with towels, and weighed. If the roots were to be analyzed, they were chopped into about one-eighth inch pieces. Two samples were taken for the determination of moisture and a sample of usually 50 or 100 grams preserved for determinations of reserve carbohydrates.

## METHODS OF ANALYSIS

The preservation of the roots was accomplished by placing them in 500-cc wide-mouth bottles or flasks containing boiling 95% ethyl alcohol, boiling the solution for about 1 hour on a hot plate, and sealing the flasks with paraffined corks.

When the samples were analyzed, the alcohol was drained from the sample by pouring the roots on a 4-inch funnel. Hot alcohol was then poured on the roots until the total volume of the filtrate was 500 cc. The filtrate was stored several days until used for the analysis of sugars. The roots on the filter paper were dried in a ventilated oven at 65° to 70°C, weighed, and then ground by means of a Wiley mill and iron mortar and pestle so as to pass a 60-mesh sieve. They were then extracted with 95% ethyl alcohol in Soxhlet extractors to remove the remaining sugars, and later used for the determination of starch and hemicellulose.

The procedure used in making the determinations of sugars, starch, and dextrins and hemicellulose was essentially the same as that used by Leukel (3), except that the reducing power of the various carbohvdrate extractions was determined by a combination of the Munson and Walker and Bertrand methods as described by Mathews (4).

Nitrogen was determined by the Kjeldahl method.

## EXPERIMENTAL DATA

### EXPERIMENT I. PRELIMINARY GREENHOUSE STUDIES WITH KUDZU PLANTS IN 4-GALLON POTS

The purpose of the first experiment was to get preliminary information regarding yield of top and reserve food storage in kudzu roots as affected by frequency of cutting. Plants were started in 32 4-gallon pots in the greenhouse in the early fall of 1925. Each pot contained 20 kg of Norfolk sandy loam soil fertilized at the beginning of the experiment with superphosphate at the rate of 600 pounds per acre and potassium chloride at the rate of 100 pounds per acre. The plants were started by imbedding nodes, from the green vines of some old plants, in the potted soil to a depth of about 1 inch. After about two weeks a good root system had started from these nodes. The vines were then cut away from the parent plant, two nodes were left to each pot, the node at which the root system started and another node with leaves which served as the point of growth for the top part of the plant. These plants made vine growths of between 2 and 4 feet in length that fall. Spring growth started in early March.

While it would seem that plants started in this manner should be very uniform, it was found that there was considerable variation in the amounts of growth. The plants were, therefore, classified and arranged as uniformly as possible into four groups of eight plants each. During the summer of 1926 each of these groups received a different cutting treatment, *viz.*, group 1, one cutting; group 2, two cuttings; group 3, four cuttings; and group 4, six cuttings. The yields secured from each plant were recorded and a sample was taken from each cutting for determination of total nitrogen.

The results secured are tabulated in Table 1. It will be noted that the greatest total yield was secured with the two-cutting treatment. The four-cutting treatment follows next in order, whereas the six-cutting treatment resulted in the lowest total yields. The relatively low yields secured from the one-cutting treatment were partly due to the fact that the plants had lost quite a number of leaves before the

cutting was made. The two-cutting treatment also resulted in the largest total amount of nitrogen produced. As would be expected, the plants from the six-cutting treatment contained the highest percentage of nitrogen; but due to the lower yields, the total nitrogen was only about two-thirds of that secured from the plants cut only twice during the season.

TABLE 1.—*Yields and percentage nitrogen in kudzu tops receiving various cutting treatments.**

| Number of cuttings | Date of cutting | Average yield per plant, grams: Per cutting | Average yield per plant, grams: Total | Percentage nitrogen | Total nitrogen per plant, mgm: Per cutting | Total nitrogen per plant, mgm: Total |
|---|---|---|---|---|---|---|
| 1 | Oct. 6 | 45.5 | 45.5 | 1.54 | 701 | 701 |
| 2 | July 3 | 34.6 | | 2.15 | 744 | |
| | Oct. 6 | 28.9 | 63.5 | 1.86 | 537 | 1,281 |
| | May 10 | 6.6 | | 1.74 | 115 | |
| 4 | July 3 | 19.9 | 50.8 | 2.16 | 430 | 1,086 |
| | Aug. 16 | 15.8 | | 2.14 | 338 | |
| | Oct. 6 | 8.5 | | 2.39 | 203 | |
| | May 10 | 6.7 | | 1.74 | 117 | |
| | June 9 | 5.1 | | 2.87 | 146 | |
| 6 | July 3 | 5.9 | 36.6 | 2.51 | 127 | 814 |
| | Aug. 4 | 10.7 | | 1.99 | 217 | |
| | Sept. 10 | 6.1 | | 2.51† | 153 | |
| | Oct. 6 | 2.1 | | 2.58 | 54 | |

*The data presented are all expressed on the dry weight basis.

†Sample lost; percentage assumed to be the same as on July 3 when about the same weight was harvested.

At the time of the last cutting, the roots were removed from the soil, thoroughly washed, and the storage and fibrous roots weighed and prepared for analysis as previously described. Since it is very difficult to retain all the fibrous roots when field plants are dug, this experiment with plants in pots was especially valuable in that it made possible a study of the fibrous as well as the storage roots of kudzu.

Table 2 presents the data secured from a study of the roots. The weight of the roots, as well as the percentage of dry matter, was markedly affected by the cutting treatments. The greater the number of cuttings the lower the yield of both storage and fibrous roots, and the smaller the percentage of dry matter in the roots. Whereas the total dry weight of the roots from the plants receiving one cutting was over 59 grams, that from the plants receiving the six-

TABLE 2.—*Carbohydrate and nitrogen storage products in 1-year old kudzu roots, the tops of which received various cutting treatments.*

| Number of cuttings | Kind of root | Dry weight, grams | Dry matter % | Reducing sugars % | Reducing sugars Grams | Non-reducing sugars % | Non-reducing sugars Grams | Starch and dextrin* % | Starch and dextrin* Grams | Hemicellulose* % | Hemicellulose* Grams | Total* carbohydrates % | Total* carbohydrates Grams | Total nitrogen % | Total nitrogen Grams |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Storage | 29.39 | 34.2 | 2.12 | 0.623 | 4.27 | 1.255 | 23.99 | 7.050 | 10.15 | 2.983 | 40.53 | 11.911 | 1.55 | 0.455 |
| | Fibrous | 29.65 | 16.1 | 1.56 | 0.463 | 1.96 | 0.581 | 3.17 | 0.940 | 12.50 | 3.706 | 19.19 | 5.690 | 2.09 | 0.620 |
| 2 | Storage | 23.87 | 36.0 | 2.18 | 0.520 | 3.60 | 0.859 | 24.13 | 5.760 | 9.95 | 2.375 | 39.86 | 9.514 | 1.43 | 0.341 |
| | Fibrous | 17.95 | 15.9 | 1.41 | 0.255 | 1.02 | 0.183 | 2.36 | 0.423 | 10.90 | 1.956 | 15.69 | 2.817 | 1.96 | 0.352 |
| 4 | Storage | 10.12 | 27.2 | 2.56 | 0.259 | 3.80 | 0.385 | 19.50 | 1.973 | 10.35 | 1.047 | 36.21 | 3.664 | 1.49 | 0.151 |
| | Fibrous | 5.70 | 15.5 | 1.47 | 0.084 | 1.73 | 0.099 | 3.67 | 0.209 | 10.05 | 0.573 | 16.92 | 0.965 | 1.83 | 0.104 |
| 6 | Storage | 5.99 | 21.1 | 3.08 | 0.184 | 3.88 | 0.232 | 8.75 | 0.524 | 10.95 | 0.656 | 26.66 | 1.596 | 1.01 | 0.060 |
| | Fibrous | 4.40 | 15.5 | 0.80 | 0.035 | 1.00 | 0.044 | 1.48 | 0.065 | 8.50 | 0.374 | 11.78 | 0.518 | 1.42 | 0.062 |
| 0† | Storage | 34.43 | —— | 1.46 | 0.503 | 3.36 | 1.157 | 35.72 | 12.298 | 8.05 | 2.772 | 48.59 | 16.730 | 1.61 | 0.554 |

*Calculated as dextrose.

†Field sample taken in February, 1927.

cutting treatment was only a little over 10 grams, or about one-sixth as much.

In regard to storage material in the roots, it will be seen that the main differences obtained in percentage are with the storage roots, and that the starch and dextrins are the main carbohydrate reserves that vary. The percentage of starch and dextrins in the roots of the plants receiving one- and two-cutting treatment was about 24, whereas it was only approximately 20 and 8, respectively, in the roots from the plants receiving the four- and six-cutting treatments. On the other hand, the reducing sugars in the storage roots increased slightly in percentage as the number of cutting treatments increased. The percentages of the various carbohydrates in the fibrous roots do not vary markedly, although the six-cutting treatment resulted in a decrease in the percentage of all the carbohydrate reserves. It will be noted that in all cases the percentages of total carbohydrates are about one-half as high in the fibrous as in the storage roots. This shows that some storage material is found in the fibrous roots. If the total amounts of carbohydrate reserves are considered, it will be seen that about eight times as much is produced in the roots of plants receiving the one-cutting treatment as in those from plants receiving the six-cutting treatment.

The percentage and total amount of nitrogen in the roots decrease with an increase in the number of cuttings given the tops. This relation is true for both storage and fibrous roots.

Table 2 also includes the weight and analysis of a storage root secured from the field in February, 1927. The top of this plant had not been cut in 1926. It will be seen that the general relation observed between number of cuttings and reserve food storage holds, for a greater amount of reserved carbohydrates is found than in the roots of plants getting one or more cutting treatments.

## EXPERIMENT II. FIELD STUDIES 1926–28, EFFECT OF CUTTING TREATMENTS ON YIELDS, INCREASES IN ROOT GROWTH, AND RESERVE FOOD STORAGE

The purposes of this experiment were the same as those of Experiment I. The work was performed in the field, however, and the plants were started by means of transplanted roots rather than by the burying of vine nodes from older plants. Moreover, cutting treatments were not started until the roots had accumulated considerable reserve food.

The plants were set out in the spring of 1926. Kudzu roots of rather small size were obtained from a nearby field and cut back to a

length of 1 foot, when necessary, to secure roots of similar size. The roots were then washed and divided into three general groups according to size. Each of these groups was again further subdivided into sub-groups of 10 and the weight of the sub-groups recorded. These sub-groups of 10 were then planted in rows across the plats. By thus keeping a record of the original weight of the roots, it was possible to make studies on the increases in root growth made from time to time (Table 3), and on the effects on plant development of planting roots of various sizes. The latter study will be discussed in Experiment IV.

TABLE 3.—*The increase in weight of roots during the first year.*

| Plant No. | Classification of plants on basis of top growth | Weight of roots, grams Original | Final | Increase in weight % | Average increase in weight % |
|---|---|---|---|---|---|
| 2/3/4 | Excellent | 16.3 | 118.0 | 624 | |
| 2/6/2 | | 29.7 | 186.0 | 526 | 575 |
| 2/4/8 | | 17.9 | 93.5 | 422 | |
| 3/2/7 | Good | 16.2 | 84.5 | 423 | 432 |
| 2/5/4 | | 26.5 | 146.0 | 451 | |
| 3/4/7 | | 18.0 | 51.5 | 186 | |
| 3/3/6 | Fair | 17.8 | 71.8 | 303 | 234 |
| 3/3/2 | | 17.8 | 55.5 | 212 | |

The tops of these plants were not cut in 1926. A considerable variation in size of tops was noticed during the growing season. It seemed desirable for the studies on cutting treatments to classify these plants into groups according to their growth. Plants which had vines 3 to 6 feet long and had made excellent growth were classified as excellent; those with vines 2 to 3 feet long, good; while the plants that had only a few small runners and had made relatively poor growth, were rated as fair. A few plants were classified as poor and were not used in the experiment. When cutting treatments were started in 1927, an effort was made to have the same number of excellent, good, and fair plants in each lot receiving different cutting treatments.

*Yields and nitrogen content of plants receiving different cutting treatments.*—In the spring of 1927, at the beginning of the second year of growth, the plants were arranged into four uniform groups of 23 to 26 plants each. Each group was given a different cutting treatment during 1927 and 1928. The four different cutting treatments represented were one, two, four, and six cuttings per season. The

yields from each plant were recorded separately. Only the averages of each group are given in Table 4.

If the yields of 1927 are first considered, it will be noted that the greatest total yield was secured with the two-cutting treatment, and that the lowest yield was secured when the tops were cut six times during the season. These results are very similar to the results obtained in Experiment I.

In 1928, the differences in yield between the plants receiving different cutting treatments were much greater than in 1927. Thus, the yield from the plants receiving six-cutting treatments was only about one-fortieth of that from the plants receiving one-cutting treatment, while in 1927 it was about one-half. As different from 1927 also, the yield from the one-cutting treatment was greater than from the two-cutting treatment. The reason for these differences will be evident when the data on root storage, presented in Table 5 are considered. While the roots from the various plats contained about the same reserve carbohydrates at the beginning of the 1927 season, a big difference existed in these at the beginning of the 1928 season due to the fact that the plants received a different number of cuttings in 1927.

The total amount of nitrogen obtained in the tops in 1927 was greatest in the plants receiving two-cutting treatments and least from the plants receiving six cuttings. This corroborates the results obtained in Experiment I.

*Increases in root growth as affected by the cutting treatment given tops.*—After the growing seasons of 1927 and 1928, a number of the roots was dug for the determinations of reserve carbohydrates and nitrogen and for the determination of the root growth made during the season. In 1927 two to four roots were dug for each class of plants in each plat, while in 1928 the plants dug were selected so as to have two from each class in each plat.

The weights are given in Table 5. Considering first the results obtained in 1927, it will be noted that the greatest increase in growth was made by the plants receiving the smallest number of cutting treatments. While the roots of the plants receiving one cutting treatment tripled their weight, those from plants receiving six cutting treatments increased their green weight for an average of only 38%. Since the percentage dry weight of roots from the six-cutting treatment was much lower than that from the other cutting treatments, as will be seen from the data in Table 6, there was actually a decrease during 1927 in the dry weight of the roots of plants of which the tops had received six cutting treatments.

TABLE 4.—*Yield of kudzu in 1927 and 1928, and the percentage and total nitrogen content produced in 1927.**

| | 1927 | | | | | | 1928 | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Number of cutting treatments | Number of plants | Date of cutting | Average yield per plant, grams: Per cutting | Average yield per plant, grams: Total | Nitrogen per plant: % | Nitrogen per plant: Grams | Number of plants | Date of cutting | Average yield per plant, grams: Per cutting | Average yield per plant, grams: Total |
| 1 | 26 | Oct. 22 | 222.0 | 222.0 | 1.47 | 3.26 | 13 | Oct. 8 | 943.0 | 943.0 |
| 2 | 23 | July 1 | 135.4 | 262.1 | 1.93 | 4.60 | 12 | July 2 | 351.1 | 457.4 |
| | | Oct. 22 | 126.7 | | 1.57 | | | Oct. 8 | 106.3 | |
| | | April 27 | 36.1 | | 2.03 | | | May 9 | 26.3 | |
| 4 | 24 | June 7 | 26.7 | 159.4 | 2.63 | 3.42 | 12 | June 5 | 26.7 | 125.2 |
| | | Aug. 6 | 68.5 | | 2.12 | | | Aug. 1 | 46.3 | |
| | | Oct. 22 | 28.1 | | 1.91 | | | Oct. 8 | 25.9 | |
| | | April 27 | 33.3 | | 2.03 | | | May 9 | 4.2 | |
| | | June 4 | 24.7 | | 2.63 | | | June 5 | 4.7 | |
| 6 | 25 | July 1 | 16.4 | 104.3 | 2.77 | 2.39 | 11 | July 2 | 5.1 | 22.4 |
| | | Aug. 6 | 17.7 | | 2.36 | | | Aug. 1 | 4.3 | |
| | | Sept. 5 | 9.1 | | 2.76 | | | Sept. 1 | 2.7 | |
| | | Oct. 22 | 3.1 | | 2.74 | | | Oct. 8 | 1.4 | |

*The data presented are calculated on the dry matter basis.

TABLE 5.—*Root growth, during 1927 and 1928, of kudzu plants the tops of which received different cutting treatments.**

| Number of cuttings | Class of plants | 1927 season: Weight at beginning, grams | 1927 season: Weight at end, grams | 1927 season: Percentage increase, Per class | 1927 season: Percentage increase, Average | 1928 season: Weight at beginning, grams | 1928 season: Weight at end, grams | 1928 season: Percentage increase, Per class | 1928 season: Percentage increase, Average |
|---|---|---|---|---|---|---|---|---|---|
| | Fair | 60 | 305 | 408 | | 305 | 1,092 | 258 | |
| 1 | Good | 108 | 357 | 230 | 305 | 357 | 1,173 | 228 | 229 |
| | Excellent | 152 | 573 | 266 | | 573 | 1,718 | 200 | |
| | Fair | 60 | 234 | 290 | | 234 | 396 | 69 | |
| 2 | Good | 108 | 308 | 185 | 211 | 308 | 500 | 62 | 61 |
| | Excellent | 152 | 390 | 157 | | 390 | 587 | 51 | |
| | Fair | 60 | 129 | 115 | | 129 | 138 | 7 | |
| 4 | Good | 108 | 224 | 107 | 114 | 224 | 357 | 59 | 23 |
| | Excellent | 152 | 278 | 121 | | 278 | 290 | 4 | |
| | Fair | 60 | 85 | 25 | | 85 | 52 | —63 | |
| 6 | Good | 108 | 139 | 29 | 38 | 139 | 92 | —51 | —53 |
| | Excellent | 152 | 244 | 61 | | 244 | 170 | —44 | |

*The weights presented are of the green roots.

During the 1928 season, the roots of the plants which received one cutting made an increase in growth of over 200%, while those from plants receiving two cuttings made an increased growth of only 61%. The roots of the plants receiving four cutting treatments made practically no growth, while those of plants receiving six cuttings actually decreased in weight.

The differences between the yields produced in 1927 and 1928 and the differences between the weight of the roots after each season are shown graphically in Fig. 1. This graph shows the additive influence of cutting treatments on yields and increases in root growth from year to year.

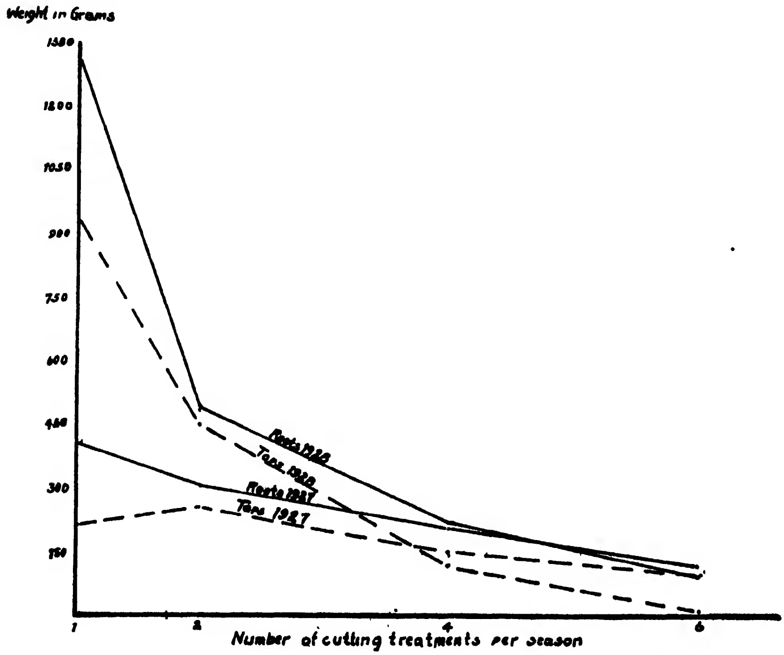


FIG. 1.—The weights of roots and the yields of tops of kudzu as affected by the number of cuttings given the tops.

*Root storage as affected by cutting treatments*.—The roots dug after the second year's growth were analyzed for total sugars, starches, and total nitrogen. Determinations of reducing sugar and hemicellulose were not made, since the results obtained in Experiment I did not seem to justify such determinations. The results of the analysis are reported in Table 6 and are shown graphically in Fig. 2. The figures given are averages of duplicate determinations.

It will be noted that the results are very similar to the results secured with the plants grown in the greenhouse in Experiment I. The percentage of starch and dextrins, calculated as dextrose, decreased materially when the plants were cut six times. On the other hand, a greater percentage of sugars was found in the roots from the plants receiving six cutting treatments. This again indicates that when the plants are cut often the starch in the roots is converted into

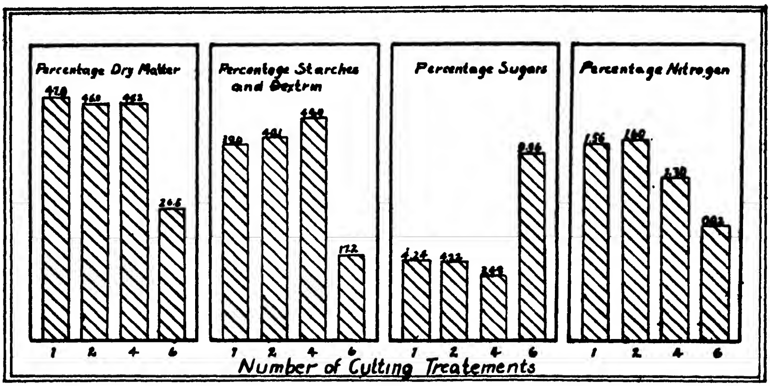


FIG. 2.—The percentage dry matter and the percentage of starches, sugars, and nitrogen (dry basis) in the roots of kudzu, the tops of which received a different number of cuttings.

sugars to produce new top growth. The percentage nitrogen rapidly decreases as the number of cutting treatments given the tops increases, thus indicating a considerable storage of nitrogen in roots of which the tops are cut less frequently. The total amounts of starch, sugars, and nitrogen given in the last three columns of Table 6 summarize very well the effect of frequent cutting treatments on the reserve food storage in the roots.

Not only do frequent cuttings influence the amount of stored products, but they also affect the percentage of water in the roots. The large increase in percentage of water in the roots of plants cut six times is in accord with the results obtained by Leukel (3) with alfalfa and indicates a possible reason why such roots would be more likely to winterkill.

## EXPERIMENT III. FORMATION OF RESERVE CARBOHYDRATES DURING THE GROWING SEASON AND EFFECT OF LATE CUTTING TREATMENTS ON THESE RESERVES

Leukel (3) has shown that for the alfalfa plant a certain amount and maturity of top growth is necessary before there is much re-

TABLE 6.—*Percentage and total amount of storage materials in kudzu roots at the end of the second year's growth of plants subjected to various cutting treatments during the second year.*

| Number of cuttings | Sample No. | Weight of green root, grams | Average percentage dry matter | Percentage (dry root basis): Starches* and dextrins, Individual plants | Starches* and dextrins, Average | Sugars, Individual plants | Sugars, Average | Nitrogen, Individual plants | Nitrogen, Average | Total amounts in average root†: Starches* and dextrins, grams | Sugars, grams | Nitrogen, grams |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2 | 616 | | 36.2 | | 4.04 | | 1.57 | | | | |
| 1 | 4 | 405 | 47.9 | 43.5 | 39.0 | 4.26 | 4.24 | 1.46 | 1.56 | 71.4 | 7.76 | 2.85 |
| | 6 | 326 | | 37.3 | | 4.21 | | 1.64 | | | | |
| | 8 | 487 | | 41.8 | | 3.98 | | 1.55 | | | | |
| 2 | 10 | 313 | 46.9 | 39.6 | 40.1 | 4.21 | 4.22 | 1.63 | 1.60 | 56.1 | 5.91 | 2.24 |
| | 11 | 297 | | 39.0 | | 4.46 | | 1.63 | | | | |
| | 14 | 344 | | 46.4 | | 3.02 | | 1.26 | | | | |
| 4 | 16 | 239 | 47.2 | 47.7 | 44.0 | 3.45 | 3.48 | 1.33 | 1.30 | 40.3 | 3.18 | 1.19 |
| | 18 | 144 | | 38.0 | | 3.98 | | 1.32 | | | | |
| | 19 | 78 | | 24.0 | | 8.84 | | 0.82 | | | | |
| 6 | 20 | 139 | 26.5 | 23.6 | 17.2 | 9.73 | 9.96 | 0.98 | 0.92 | 5.7 | 3.33 | 0.31 |
| | 22 | 288 | | 4.0 | | 11.30 | | 0.97 | | | | |

*Calculations were made on the basis of the average weight of all the roots dug.
†Calculated as dextrose.

TABLE 7.—*Percentages of sugars, starches, and nitrogen in kudzu roots at different times during the growing season.*

| Sample No. | Class of plants | Date of digging | Weight of roots, grams | Dry matter % | Sugars Individual plants % | Sugars Average % | Starches* Individual plants % | Starches* Average % | Nitrogen Individual plants % | Nitrogen Average % |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Fair | | 55 | | 5.7 | | 29.3 | | 1.97 | |
| 2 | Excellent | April 2 | 302 | 34.3 | 5.3 | 5.0 | 32.8 | 31.5 | 2.06 | 2.06 |
| 3 | Good | | 153 | | 4.1 | | 32.4 | | 2.20 | |
| 5 | Good | June 4 | 165 | 44.5 | 4.6 | — | 30.2 | 31.2 | | |
| 6 | Poor | | 127 | | 16.2 | | 32.2 | | | |
| 7 | Fair | | 98 | | 3.8 | | 30.6 | | 1.08 | |
| 8 | Good | Aug. 6 | 246 | 40.1 | 4.8 | 4.3 | 30.0 | 30.1 | 1.03 | 1.04 |
| 9 | Excellent | | 448 | | 4.4 | | 29.6 | | 1.01 | |
| 10 | Fair | Sept. 5 | 179 | 42.2 | 14.9 | — | 29.2 | 29.2 | 1.18 | 1.18 |
| 12 | Good | Oct. 22 | 760 | 46.7 | 3.9 | 4.6 | 47.9 | 46.7 | 1.60 | 1.58 |
| 12A | Good | | 1094 | | 5.3 | | 45.4 | | 1.56 | |
| 14 | Fair | Dec. 6 | 352 | 45.6 | 3.8 | 3.8 | 43.0 | 43.0 | | |

*Calculated as dextrose.

plenishment of the reserve foods of the roots. He also found that cutting the tops before they had obtained this growth resulted in an actual reduction of the organic root reserves and a decreased vigor of the plant. It seemed desirable, therefore, to study the time of formation of the reserve foods in kudzu roots to ascertain, if possible, when and how late cutting treatments should be made.

The plants used in this experiment were grown similarly to those in Experiment II. The tops were not cut during the growth of the plants, except when the roots were dug sometime during the second growing season, their weights recorded, and samples taken for determinations of total sugars, starch, and total nitrogen. The results of the study are given in Table 7.

It will be noted that, with the exception of two roots, numbers 6 and 10, the percentages of sugar do not vary much during the growing season. The high results secured in these two roots seem difficult to understand. It seems more likely, however, that some error was made or that some changes in the storage material took place during the preservation period of these samples than that these values represent the true percentage of sugars found in the roots.

The results indicate that starch and dextrins form the chief storage products. The significant point in this respect is that the percentage of starch remains very constant until sometime in September, after which time an increase rapidly takes place. The percentage was 29.2, calculated as dextrose, on September 5, while it was 46.7 on October 22.

While the number of roots dug is too small to permit an accurate study of the increase in root growth during the season, the data on weight of roots indicate that there is actually a considerable storage of starch before September due to the fact that the roots are gradually getting larger. If we compare plants of the same classification, such as the "Fair" plants, it will be noted that the roots increased in weight from 55.5 grams on April 2, to 98 grams on August 6, to 179 grams on September 5, and to 352 grams on December 6. A similar comparison of plants classified as "Good" shows the same gradual growth of roots during the season. Although these figures are only approximate, they no doubt represent fairly accurately the true situation. It seems, therefore, that the plants during the early part of the growing season store starch and dextrins by maintaining a very uniform percentage of these products in their roots, which are continually enlarging; and that it is only during the very last part of the season, when top growth has nearly ceased, that starch and dextrins are stored in the roots by means of an increase in their concentration.

These results are different than those obtained by Leukel (3) with

alfalfa. Leukel obtained a minimum in the percentage of starch in the roots in August, when the plants were in the seed-pod stage of growth, and a lower percentage of starch in the dormant stage on December 6 than at any time between May 26 and July 10. On the other hand, he obtained a higher percentage of total sugars on December 6 than on any other date. Possibly these differences may be explained in part by the fact that alfalfa plants reach definite stages of maturity, while kudzu plants under our conditions very seldom bloom. These data will be discussed further in connection with the discussion of lateness of cutting.

The data in regard to nitrogen show that the percentage of nitrogen is high at the beginning of the growing season and gradually decreases as the season progresses until sometime in August. Then there is a gradual increase or storage to the end of the growing season.

*Effect of late cuttings on the percentage of reserve foods.*—In order to determine the effect of late cuttings on the reserve food storage, a number of plants grown similarly to those in the experiment just described were cut on September 5, and a similar group left uncut. On October 22 and December 6 several plants from each group were dug, and the roots weighed and analyzed for starch, sugar, and percentage dry matter. The data are recorded in Table 8.

It will be noted that the effect of cutting the tops of plants on September 5 has been to increase slightly the percentage of sugars in the roots and to cause a decided decrease in the percentage of starch and dry matter. Although only a small growth of top was made after the cutting of September 5, there was lost from the roots over one-half their content of starch in order to make this scant top growth. The roots in losing their starch absorb considerable water. These results would seem to explain the fact that late cuttings result in a greater amount of winterkilling.

The question as to how late the last cutting can be made without leaving the roots of the plants low in starch and high in water at the end of the season is, therefore, a practical one. These data indicate that September 5, under conditions at this station, is too late. If we examine the data presented in Table 6, it will be noted that the plants receiving the four-cutting treatment were cut for the third time on August 6. On October 22, when the plants were again cut and the roots dug, it will be noticed that the percentage of starch and the percentage of dry matter are about the same as when the plants had not been cut at all during the season. This shows that if the last cutting is made in the early part of August the roots still have plenty of time to build up a high starch reserve and to regain their normal dry matter content.

TABLE 8.—*Percentages of sugars, starches, and dry matter in the roots of kudzu as affected by late cutting of tops.*

| Sample No. | Date of digging | Date of previous cutting | Weight of tops, grams | | Weight of root, Oct. 22, grams | Sugars | | Starches* | | Dry matter | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Sept. 5 | At digging | | Individual plants | Average | Individual plants | Average | Individual plants | Average |
| | | | | | | % | % | % | % | % | % |
| 12 | Oct. 22 | None | — | 325 | 760 | 3.9 | 4.6 | 47.9 | 46.7 | 47.2 | 45.6 |
| 12A | | | — | 530 | 1094 | 5.3 | | 45.4 | | 43.9 | |
| 11 | Oct. 22 | Sept. 5 | 385 | 33 | 393 | 5.9 | 5.9 | 14.8 | 19.0 | 32.5 | 30.8 |
| 11A | | | 339 | 12 | 328 | 5.9 | | 23.2 | | 29.0 | |
| 14 | Dec. 6 | None | — | 155 | 352 | 3.8 | 3.8 | 43.0 | 43.0 | 45.6 | 45.6 |
| 13 | Dec. 6 | Sept. 5 | 179 | 7 | 222 | 4.7 | 4.7 | 16.9 | 16.9 | 27.5 | 27.5 |

*Calculated as dextrose.

## EXPERIMENT IV. RELATION BETWEEN SIZE OF ROOTS PLANTED AND PERCENTAGE OF SUCH ROOTS THAT WILL LIVE AND MAKE GOOD GROWTH

The plants used in Experiment II had been weighed before planting and therefore furnish some data for the present study. These data are presented in Table 9. It will be noted that a considerably greater percentage of the roots which weighed 28 grams when transplanted lived than the roots which weighed only 14 grams. Moreover, the former produced over two and one-half times as many plants classified as "Excellent" than the latter.

TABLE 9.—*Total number and percentage of transplanted roots of various sizes that lived and made good growth (1926).*

| Average weight of roots, grams | Plants living on Nov. 9 | | Plants making excellent growth | |
|---|---|---|---|---|
| | Number | % | Number | % |
| 14.7 | 34 | 42.5 | 13 | 16.2 |
| 17.2 | 37 | 46.3 | 23 | 28.7 |
| 28.3 | 53 | 66.2 | 33 | 41.2 |

The percentage of plants living is rather low in any case. This is explained by the fact that the roots were planted on April 1, which is considered too late for the best results, and that the early growing season of 1926 was very dry.

In order to get more data on this question, a similar experiment was started in 1928. Six plats, each one twenty-second of an acre in size, were planted with roots spaced 6 feet apart in 6-foot rows. Two plats were planted with roots averaging 82 grams in weight each; two with roots averaging 156 grams; and two with roots averaging 268 grams each. The roots were set out on March 1.

The results of the first year of growth are shown in Table 10. It will be noted that an average of 98% of the plants lived and that there was no significant difference in this respect between the various plats. The average length of vines made by the roots of various sizes, however, varied markedly. For example, nearly twice the length of vine growth was made by the roots which weighed 268 grams as by those that weighed 82 grams. It is fair to conclude that the greater the carbohydrate reserve of the roots or the larger the roots used in planting a field with kudzu, the quicker will a stand be secured, and the sooner cuttings can be started. If unfavorable conditions of growth exist, it is also seen that the larger the roots used, the greater is the percentage of plants that will survive.

TABLE 10.—*Percentage of plants living and the rate of depelopment of plants from transplanted roots of various sizes (1928)**.

| Plat No. | Average wieght of roots, grams | Average diameter of roots, inches | Dead plants Number | Dead plants Average % | Average length of vine growth made per plant, 1928 Individual plat, feet | Average length of vine growth made per plant, 1928 Average, feet |
|---|---|---|---|---|---|---|
| 1 | 82 | 3/8 | 2 | 3.2 | 15.5 | 17.3 |
| 4 | | | 1 | | 19.0 | |
| 2 | 156 | 5/8 | 1 | 1.1 | 20.7 | 21.7 |
| 5 | | | 0 | | 22.7 | |
| 3 | 268 | 1 | 1 | 2.1 | 29.7 | 30.4 |
| 6 | | | 1 | | 31.1 | |

*Each plat was planted with 48 roots.

## GENERAL DISCUSSION AND PRACTICAL CONSIDERATIONS

The general results obtained in this investigation in regard to the relation between cutting treatment, yields, and reserve food storage in kudzu roots agree well with the results of Nelson (5), Leukel (3), and Albert (1), working with alfalfa at the Wisconsin Experiment Station. The results with kudzu, however, are even more pronounced than those obtained by these investigators with alfalfa. This is no doubt due to the fact that this plant has a very high capacity for reserve food storage. Willard (10) called attention to the enormous root system of kudzu and states that roots were found to extend 6½ feet into the soil.

Starch was found to be the main carbohydrate storage product. In some of the roots the starch, calculated as dextrose, was found to amount to over 47%. The greatest amount of total starch and dextrins found in alfalfa by Leukel was about 32%, calculated on a similar basis.

The results obtained in Experiments I and II show that root storage is dependent on a vigorous top growth and that, in turn, the subsequent growth of tops is affected largely by the reserve food storage in the roots. Frequent cutting treatments were found to inhibit a reserve food storage in the roots. In fact, there was an actual decrease in the weight of the roots when the plants were cut six times during the season. On the other hand, the roots increased over 300% in one year when the tops were cut only once during the season. The deleterious effect on root growth and storage of continuing the frequent cutting treatments from year to year is additive. For example, the roots, the tops of which received four cuttings, made practically no increased growth the second year of treatment,

while they made increased growth of over 100% the first year. The explanation of these results lies in the fact that the total yield of tops decreases with increase in number of cutting treatments and that the amount of top growth determines the amount of root storage.

Not only is the total amount of root storage affected by cutting treatments, but the percentage of reserve starch and nitrogen is also markedly affected. The percentage of nitrogen found gradually decreases as the number of cutting treatments increases, but the percentage of starch drops suddenly when the cutting treatments reach a certain number which in the field experiment reported was six. Thus, the percentage of starch and total reserve carbohydrates was less than one-half as much in the roots, the tops of which received six cutting treatments, as in the roots the tops of which received four or fewer cutting treatments. During the first year the greatest yield of tops in the field was obtained from the two-cutting treatment, but the second year the greatest yield was obtained from one cutting. This is explained by the greater amount of root storage made during the first year by the plants receiving only one cutting.

In practice, then, What is the best number of cutting treatments for kudzu? In answering this question various factors must be taken into consideration. Among these factors are the fertility of the soil, the quality of hay desired, the age of the plants when cutting treatments are started, and how permanent a stand is desired. The limited extent of this investigation does not permit a full evaluation of each of these factors, but certain important facts are brought out from which general recommendations may be made.

In the first place, it should be the policy to plant as large roots as is consistent with convenience and cost. If possible, roots weighing at least 100 grams should be used. Moreover, care must be taken that neither the root nor the crown is injured. Second, since the total amount of top growth is so closely dependent on the amount of reserve root storage, it should be a primary consideration of every grower to allow the plants to build up a good root system before starting to cut the tops and to adjust the number of cuttings so that the root reserves are not continually depleted. The plants should be allowed to grow two years, if possible, before starting to harvest the tops. If they are harvested the second year, the number of cuttings should be kept to one or at the most two. This does not necessarily mean that the land will yield nothing for two years, for it is possible to grow other crops between the kudzu plants for at least the first year.

The number of cuttings per year will depend somewhat on the fertility of the soil. Unless the land is very fertile, in which case top growth would be very rapid, it would seem that the two-cutting treatment is the most desirable. While the one-cutting treatment late in the season may result in a greater total yield, especially if cutting treatments are started before the roots are very large or have had a chance to store much reserve food, the quality of the hay is much poorer. Moreover, there is considerable difficulty in cutting and handling the hay when the tops are cut only once during the latter part of the season. The two-cutting treatment allows for sufficient root storage to permit the maintenance of a good stand, and to allow the production of high yields and a hay of good quality. If the field is grazed, it should not be grazed too closely at any time, nor very late in the fall.

The question as to how late cuttings can be made can be answered only very tentatively. From the results obtained, however, it would seem that there is little to be gained in additional yields from delaying the last cutting until after the first of September. Under the conditions of these experiments, it was seen that cutting as late as September 5 caused a material reduction in the percentage of carbohydrates in the roots and caused a marked increase in the percentage of water. These two changes are believed to lower the vitality of the plant and its ability to resist injury from freezing. While additional experiments are needed to clarify the practical aspects of this question, it is believed that the best results will be obtained by making the last cutting sometime before the first of September.

Additional experiments are being conducted at this station in order to get more data on this question and on the question of number of cutting treatments as affecting total yield and permanency of stand. A number of small plats were started in 1926 and cutting treatments were started on these in 1928. While it is still too early to draw conclusions from these plats, the results obtained thus far are in accord with our general conclusions.

It may be of some interest to note the yields obtained in 1928 on these plats. With two cutting treatments the yields averaged 5,561 pounds per acre; with three cuttings, 4,417 pounds; and with four cuttings, 3,820 pounds. The yields secured with the two-cutting treatment are much the same as those secured for an average of six years on another field of the station farm (2). They are considerably lower than have sometimes been reported for kudzu (6), but it must be remembered that the soil used in these experiments is a rather poor, unfertilized loamy sand.

These yields show the possibility of kudzu on the many acres of land continually being abandoned for cultivation in many sections of the southern states. If these abandoned fields could be planted with kudzu, they would soon be protected from further erosion and would be built up in fertility to the extent that they could again be profitably brought back into cultivation. In an experiment being conducted at this station on the value of kudzu as a soil builder, it was found that even after nine years the effect of turning under a stand of kudzu can still be noted in the yields of corn and oats obtained.

## SUMMARY

Experiments with kudzu regarding the effect of number of cutting treatments on yields and on the production of reserve foods in the roots brought out the following facts:

1. The fewer the number of cuttings the greater is the production of root reserves. The roots of plants receiving six cuttings per season decreased in weight during a period of two years, those from plants receiving four cuttings increased about 150%, those from plants receiving two cuttings increased approximately 400%, and those from plants receiving one cutting increased about 1,250%.

2. Yields of top were found to be dependent on the amount of reserve food stored in the roots. The greater the amount of root storage, the greater is the yield of top.

3. The greatest yield of tops was secured with the two-cutting treatment when the roots were of equal size at the beginning of the experiment. Due to the greater amount of storage material formed in the roots during the first year from plants cut only once, however, the greatest yield secured the second year was from the one-cutting treatment.

4. The percentage of reserve starch and nitrogen was found to be less than one-half as much in the roots from plants receiving six cuttings as in the roots of plants receiving four or a less number of cuttings. The percentage of total sugars, however, was found to be greater. This is taken to indicate that a change from starch to sugar is taking place in the roots of plants receiving six cuttings in order to produce new top growth.

A study of the changes during the season in the reserve food storage of the roots of plants receiving no cuttings and the effect of late cutting on these reserves gave the following results:

1. The percentage of sugar did not change materially during the season.

2. The percentage of nitrogen was high at the beginning of the season and gradually decreased, while growth was rapid until sometime in August. Then, it again increased until the end of the season.

3. The percentage of starch and dextrins remained very constant until sometime in September and then increased very markedly from about 30 to 45%, calculated as dextrose.

4. Cutting the tops as late as September 5 caused a marked reduction in the percentage of starch and dextrins and an increase in the percentage of sugars and water found in the roots for the remainder of the season.

Studies made in order to determine the effects of planting various sized roots on the vigor of the plants showed that the top growth from large roots was much more rapid than from small roots. This was taken as additional evidence that top growth is dependent to a large extent on the reserve storage materials in the roots. The practical field applications of these results are discussed.

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# A COMPARISON OF FIELD METHODS OF DETERMINING SOIL REACTION[1]

A. B. BEAUMONT AND C. H. THAYER[2]

Due largely to improvement of methods, the interest in the estimation of soil reaction in the field has been revived in recent years. This in turn has stimulated the placing on the market of devices designed to meet the growing demand. Most of the new devices offered make use of the principle of color changes of acid-base indicators. In addition, some use has been made of color changes accompanying specific chemical reactions, such as that between soluble iron and potassium thiocyanate.

Historically, it is interesting to note that the first widely used field method of testing soil reaction also involved the use of an acid-base indicator, litmus. For many years, the litmus paper method was practically the only one used in the field. The $NH_4OH$ method proposed by Müntz and cited by Lyon, *et al.* (2)[3] depended on the presence of humified organic matter and never became popular in this country. Just when and by whom litmus was first used for testing soil reaction is not known to the writers. It is known, however, that it was used by Voelcker (6) as early as 1865. Due largely to the advocacy of its use by Wheeler and coworkers (7), who used it in testing acid upland soils of Rhode Island in the 1890's, it became popular among the soil workers of the United States in the first part of the present century.

Litmus paper was used for testing soil reaction almost exclusively until the advent of Truog's (5) ZnS method in 1914. In 1920, Comber's (1) method was published, and in 1924 Spurway (4) showed how the indicator brom-thymol blue could, with facility, be used in testing the reaction of soils in the field. Since then, several devices have been placed on the market under various trade names, all making use of indicators in some way.

Also, some attempts, accompanied by more or less success, have been made to use the potentiometer in the field. Since equipment involving the use of the potentiometer is very expensive as compared with that using indicators, and also cumbersome to handle in the field, it is unlikely to be widely used for field work. However, there may be special conditions under which electrometric methods can be effectively used in the field.

[1]Contribution No. 99 from the Massachusetts Agricultural Experiment Station, Amherst, Mass. Received for publication May 2, 1929.

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[3]Reference by number is to "Literature Cited," p. 1108.

TABLE 1.—*Reaction of various soils as determined by observer A.*

| Soil No. | Litmus | Soiltex | Richorpoor | Truog | Teskit | Morgan | Potentiometer | Active acidity |
|---|---|---|---|---|---|---|---|---|
| 1 | Slight | Medium | None | Very slight | 4.5 | 6.6 | 5.8 | 16 |
| 2 | Strong | Very strong | Slight | Very strong | 4.5 | 5.4 | 4.7 | 200 |
| 3 | Strong | Very strong | Slight | Slight | 5.5 | 5.0 | 5.6 | 25 |
| 4 | Neutral | Alkaline | None | None | 7.5 | 7.9 | 8.1 | —12.5 |
| 5 | Medium | Strong | None | Slight | 4.5 | 5.6 | 5.8 | 16 |
| 6 | Very strong | Strong | Slight | Very strong | 4.5 | 4.6 | 4.4 | 400 |
| 7 | Strong | Very strong | Slight | Strong | 4.5 | 4.8 | 4.4 | 400 |
| 8 | Medium | Very strong | None | Medium | 4.5 | 5.8 | 5.2 | 63 |
| 9 | Strong | Strong | Very slight | Medium | 4.2 | 5.1 | 5.2 | 63 |
| 10 | Medium | Slight | None | Slight | 5.0 | 6.4 | 6.1 | 8 |
| 11 | Strong | Strong | Strong | Very strong | 4.3 | 4.4 | 4.9 | 125 |
| 12 | Slight | Slight | None | Slight | 4.6 | 6.9 | 6.3 | 5 |
| 13 | Slight | Medium | None | Neutral | 6.7 | 6.5 | 6.5 | 3 |
| 14 | Medium | Strong | None | Very slight | 4.5 | 6.2 | 6.4 | 4 |
| 15 | Slight | Strong | None | Very slight | 5.0 | 6.0 | 6.4 | 4 |
| 16 | Strong | Very strong | Slight | Strong | 4.2 | 5.1 | 5.0 | 100 |
| 17 | Strong | Very strong | Medium | Very strong | 4.2 | 4.0 | 4.0 | 1,000 |
| 18 | Strong | Very strong | Medium | Strong | 4.3 | 4.0 | 3.9 | 1,250 |
| 19 | Medium | Strong | Very slight | Strong | 4.9 | 5.2 | 4.7 | 200 |
| 20 | Medium | Slight | None | Slight | 4.9 | 6.6 | 6.0 | 10 |

TABLE 2.—*Reaction of various soils as determined by observer B.*

| Soil No. | Litmus | Soiltex | Richorpoor | Truog | Teskit | Morgan | Potentiometer | Active acidity |
|---|---|---|---|---|---|---|---|---|
| 1 | Slight | Strong | None | Very slight | 4.5 | 6.6 | 5.8 | 16 |
| 2 | Strong | Very strong | Slight | Strong | 4.0 | 6.0 | 4.7 | 200 |
| 3 | Strong | Strong | Slight | Slight | 5.0 | 5.0 | 5.6 | 25 |
| 4 | Neutral | Alkaline | None | None | 7.5 | 7.7 | 8.1 | —12.5 |
| 5 | Medium | Strong | None | Slight | 4.5 | 6.4 | 5.8 | 16 |
| 6 | Very strong | Very strong | Slight | Very strong | 4.0 | 4.6 | 4.4 | 400 |
| 7 | Medium | Strong | Slight | Very strong | 4.0 | 4.2 | 4.4 | 400 |
| 8 | Slight | Very strong | None | Strong | 4.5 | 6.2 | 5.2 | 63 |
| 9 | Medium | Very strong | Slight | Medium | 4.0 | 5.2 | 5.2 | 63 |
| 10 | Slight | Strong | None | Slight | 5.0 | 6.3 | 6.1 | 8 |
| 11 | Strong | Very strong | Strong | Strong | 4.0 | 4.4 | 4.9 | 125 |
| 12 | Slight | Medium | None | Very slight | 6.5 | 6.6 | 6.3 | 5 |
| 13 | Slight | Strong | None | None | 5.0 | 6.0 | 6.5 | 3 |
| 14 | Medium | Strong | None | Very slight | 4.0 | 6.2 | 6.4 | 4 |
| 15 | Slight | Strong | None | Very slight | 4.5 | 6.0 | 6.4 | 4 |
| 16 | Medium | Very strong | Slight | Very strong | 4.0 | 5.1 | 5.0 | 100 |
| 17 | Medium | Very strong | Medium | Very strong | 4.0 | 4.2 | 4.0 | 1,000 |
| 18 | Very strong | Very strong | Medium | Very strong | 4.0 | 3.8 | 3.9 | 1,250 |
| 19 | Medium | Very strong | Slight | Medium | 4.0 | 4.8 | 4.7 | 200 |
| 20 | Neutral | Medium | None | Slight | 5.5 | 6.8 | 6.0 | 10 |

The data reported in this paper were collected for the purpose of giving field workers a basis for a comparison of some of the more widely known methods. Of the 20 soils tested, all but 2, numbers 3 and 4, came from Massachusetts and ranged in texture from a heavy clay loam to a very light sandy loam. Number 3 was a silt loam from western Kentucky and number 4 a black clay loam derived from limestone from north-central Texas. Samples 1 to 13 were air-dry and samples 14 to 20 moist when tested.

Since individuality is thought to be an important factor in colorimetic work, the test was designed to give some information as to differences between individual operators. Table 1 gives data secured by observer A, Table 2 those of observer B. The potentiometer readings were made with a standard potentiometer connected with a quinhydrone electrode and by the two observers working together. The figures for "active" acidity were taken from the table given by Wherry (8), and mainly for the purpose of showing the variation in H-ion concentration corresponding to given pH values.

TABLE 3.—*Deviation of readings by Teskit and Morgan's method from those with potentiometer.*

| Deviation | Teskit | | Morgan | |
|---|---|---|---|---|
| pH units | A | B | A | B |
| 0.0 | 0 | 1 | 2 | 1 |
| 0.1 | 3 | 1 | 3 | 2 |
| 0.2 | 3 | 1 | 4 | 6 |
| 0.3 | 0 | 0 | 1 | 1 |
| 0.4 | 2 | 2 | 2 | 2 |
| 0.5 | 0 | 1 | 2 | 2 |
| 0.6 | 2 | 2 | 4 | 2 |
| 0.7 | 1 | 3 | 1 | 0 |
| 0.8 | 1 | 0 | 1 | 2 |
| 0.9 | 0 | 1 | 0 | 0 |
| 1.0 | 1 | 1 | 0 | 1 |
| 1.1 | 2 | 1 | 0 | 0 |
| 1 2 | 0 | 1 | 0 | 0 |
| 1.3 | 2 | 2 | 0 | 1 |
| 1.4 | 1 | 0 | 0 | 0 |
| 1.5 | 0 | 1 | 0 | 0 |
| 1.6 | 0 | 0 | 0 | 0 |
| 1.7 | 1 | 0 | 0 | 0 |
| 1.8 | 0 | 0 | 0 | 0 |
| 1.9 | 1 | 1 | 0 | 0 |
| 2.0 | 0 | 0 | 0 | 0 |
| 0.1–0.5 | 8 | 6 | 14 | 14 |
| 0.6–1.0 | 5 | 7 | 6 | 5 |
| 1.1–1.5 | 5 | 5 | 0 | 1 |
| 1.6–2.0 | 2 | 1 | 0 | 0 |
| over 2.0 | 0 | 1 | 0 | 0 |

Of the methods[4] studied, Teskit and Morgan's were designed to give numerical results in terms of pH units. It was possible, therefore, to make numerical comparisons between the readings by these methods and those of the potentiometer. Table 3 gives deviational data.

TABLE 4.—*Essential agreement with potentiometer.*

| | A | | B | | Average A and B |
|---|---|---|---|---|---|
| | Number | % | Number | % | % |
| Litmus | 16 | 80 | 10 | 50 | 65 |
| Soiltex | 15 | 75 | 14 | 70 | 73 |
| Richorpoor | 6 | 30 | 6 | 30 | 30 |
| Truog | 13 | 65 | 13 | 65 | 65 |

In Table 4 an attempt was made to tabulate the degree of essential agreement between methods not giving numerical readings and the potentiometer. In working out this table the following numerical relationship, essentially that formerly used with Soiltex, was used as a basis:

| | |
|---|---|
| Alkaline | 7.3 + pH |
| Neutral | 6.8 — 7.2 pH |
| Slightly acid | 6.7 — 6.2 pH |
| Medium acid | 6.1 — 5.7 pH |
| Strongly acid | 5.6 — 5.0 pH |
| Very strongly acid | 4.9 — pH |

The data show, first, that the agreement between the data of colorimetric field methods and those of the potentiometer is not very perfect. Agreement was best when several indicators were used as compared with one or a combination of two (duplex indicator, Teskit). Best agreement with the potentiometer was obtained with the Morgan outfit. With this, 50% of the readings came within 0.3 unit, and 70% within 0.5 unit of the corresponding electrometric readings with both observers. With observer A, all readings with the Morgan outfit came within 0.8 unit, but with observer B there was one deviation of 1.0 unit and one of 1.3 unit. Deviations of more than 0.5 pH unit, in the opinion of the writers, indicate poor agreement. In this work it was found that the indicators used in the Morgan outfit tended to become alkaline on standing in the glass bottles. It was found necessary to add a few drops of dilute acid occasionally in order to keep the indicators at the proper working re-

[4]Soiltex is the trade name of a device which uses a solution of brom-thymol blue. Richorpoor is the trade name of a preparation similar if not identical with the alcoholic solution of potassium thiocyanate employed by Comber. Teskit is a trade device making use of a so-called duplex indicator. The Morgan outfit (3) consists of a set of four indicators and a special porcelain test block.

action. This situation will probably be found to exist with all indicators kept in the common glass bottle.

With Teskit, agreement with the potentiometer was only about one-half that with Morgan's outfit. Teskit appears to be less reliable for medium and slightly acid soils, than for strongly and very strongly acid soils. For soils of slight to medium acidity, Soiltex was found to give results more essentially in agreement with the potentiometer than did Teskit.

In the interpretation of pH units, it should be borne in mind that the pH values are logarithmic, and therefore the absolute concentration of H-ions increases much more rapidly (ten-fold) than the pH values decrease. (See last column of Tables 1 and 2.) For example, the "active" acidity corresponding to pH 6 is 10; pH 5.0, 100; and pH 4.0, 1,000.

Of the four methods whose results are measured by means of descriptive terms only, Soiltex gave most dependable results as shown by the data of Table 4. Litmus showed very favorably in comparison with Soiltex, but readings as between the two operators were quite inconsistent. In the opinion of the writers, one of the greatest objections to the use of litmus paper is the inconsistency of results. In the hands of more or less skilled technicians, working under laboratory conditions, litmus paper is dependable for approximate results.

The ZnS method of Truog primarily qualitatively measures the absorption of Ca by soils, but as shown by the data, it also gives quite dependable indications of soil reaction. The KCNS (Richorpoor) method does not give dependable results for Massachusetts soils, if the data secured can be taken as criteria.

The results of this comparative test show that the individuality of the operator is an important factor in the use of colorimetric field methods for estimating soil reaction. The writers recognize that other operators have and may obtain a closer agreement of results from some or all the methods used with those of the potentiometer, but they believe that their results are fairly representative of the average. At best, colorimetric estimations of soil reaction should be considered as approximate and as substitutes for the more accurate readings with the potentiometer.

## SUMMARY AND CONCLUSIONS

1. Six well-known methods of estimating soil reaction in the field have been compared. Twenty soils, all but two from Massachusetts, having a wide range of texture and reaction, have been used. Observations were made by two operators.

2. The test shows that colorimetric field methods may yield data that deviate widely from those secured with the potentiometer. They also show that the individuality of the operator is an important factor in the manipulation and in the interpretation of results.

3. Of the devices and methods studied, the one using several indicators, represented by Morgan's outfit, showed the closest agreement with the potentiometer. However, with this method, there were some cases of wide deviation.

4. Soiltex, using the single indicator bromthymol-blue showed second best. Litmus paper gave good results, but marked by inconsistencies as between the two operators. Truog's ZnS method, while primarily a method for estimating Ca absorption, showed up well as an indicator of soil reaction. Richorpoor (KCNS) and Teskit did not give dependable results.

5. Colorimetric methods for estimating soil reaction should, at best, be considered substitutes for the more exact and reliable electrometric methods.

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# EFFECT OF SMUT INFECTION ON THE YIELD OF SELFED LINES AND $F_1$ CROSSES IN MAIZE[1]

L. R. JORGENSON[2]

## INTRODUCTION

Corn smut, due to *Ustilago zeae* (Beckm) Unger, is one of the common plant diseases in the United States. Estimates (5)[3] of losses from this disease, frequently as high as 10% in certain states, and at 1.7% for the entire United States' crop of nearly three billions of bushels, have been made (1922–27). Only a limited number of studies of the extent of corn injuries by smut have been made. Opportunity to study this question was presented at Columbus, Ohio, in 1928, where a large number of selfed lines and crosses of corn were grown.

## MATERIAL AND METHODS

The inbred lines used had been self pollinated for four generations. The $F_1$ crosses were made between lines self pollinated for eight or more generations. The lines and crosses were grown under epidemic conditions in individual rows, the plants spaced about a foot apart. Two adjacent plants subjected to the same competition, one of which was smutted and the other smut free, were compared. Only those pairs were used in which there were no obvious differences except smut.

At harvest the ears were tagged to indicate the source, and the location of the gall was noted on the tags of the smutted plants. The size of the galls was not noted. In the selfed lines no pair was used in which one of the members was barren. There were no barren uninfected plants among the crosses. Here barrenness might reasonably be considered to be due solely to smut infection and, accordingly, no rejections were made because of barrenness. The ears were oven dried to a content of approximately 4% of moisture and then shelled. The difference between the yields of the smutted plant and the smut-free plant of each pair was obtained and Student's (3, 4) tables were used to determine the statistical significance of the mean of these differences.

[1]This study is a part of the general program of corn breeding conducted cooperatively by the Department of Agronomy, Ohio Agricultural Experiment Station, the Department of Farm Crops, Ohio State University, and the Bureau of Plant Industry. U. S. Dept. of Agriculture. Received for publication May 4, 1929.

[2]Assistant Agronomist, Office of Cereal and Crops Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, and Assistant in Agronomy, Ohio Agricultural Experiment Station. The writer wishes to thank M. T. Meyers for the seed stock used, which was developed under his supervision.

[3]Reference by number is to "Literature Cited," p. 1112.

TABLE 1.—*Yields of comparable smutted and smut-free corn plants of lines previously selfed for four generations and of $F_1$ crosses between selfed lines, at Columbus, Ohio, in 1928.*

| Location of smut gall | Number of paired comparisons | Mean yield of plants in grams of shelled grain Smut-free | Smutted | Difference in yield in per cent (lower yield of smutted plant) | Odds that the difference in yield is not due to chance |
|---|---|---|---|---|---|
| | | Selfed Lines | | | |
| Base | 4 | 59 | 36 | 39 | 2:1 |
| Lower ear or lower ear shoot | 8 | 89 | 51 | 43 | 35:1 |
| All locations below the upper ear | 12 | 79 | 46 | 42 | 28:1 |
| Upper ear | 20 | 60 | 27 | 55 | 2,499:1 |
| Shoots between the upper ear and neck | 9 | 83 | 60 | 28 | 9:1 |
| Neck | 6 | 86 | 75 | 13 | 3:1 |
| Tassel | 3 | 58 | 75 | —29 | 3:1 |
| All locations above upper ear | 18 | 80 | 67 | 16 | 7:1 |
| All locations | 50 | 69 | 42 | 39 | >10,000:1 |
| | | $F_1$ Crosses | | | |
| Base | 7 | 113 | 77 | 32 | 21:1 |
| Shoots between the base and lower ear | 3 | 127 | 47 | 63 | 7:1 |
| Lower ear or lower ear shoot | 100 | 116 | 90 | 22 | >10,000:1 |
| All locations below upper ear | 110 | 116 | 88 | 24 | >10,000:1 |
| Upper ear or upper ear shoot | 160 | 101 | 26 | 74 | >10,000:1 |
| Shoots between upper ear and neck | 111 | 108 | 34 | 69 | 19:1 |
| Neck | 79 | 126 | 83 | 34 | >10,000:1 |
| Tassel | 4 | 64 | 41 | 36 | 9:1 |
| All locations above upper ear | 94 | 121 | 75 | 38 | >10,000:1 |
| All locations | 366 | 111 | 56 | 50 | >10,000:1 |

## EXPERIMENTAL DATA

Data on the yields of inbred lines are contained in Table 1. The differences ranged from 13 to 55%. The greatest difference occurred when the smut was located on the ear, the odds being 2,944:1 that the difference was not due to the errors of random sampling. The tassel-infected plants yielded more than the smut-free plants, but only three pairs were available and the odds are but 3 : 1. The differences in yield when the smut galls were located below the ear were greater than those where the smut galls were above the ear, but in the latter case the odds are only 7 : 1. The smutted plants as a group yielded 39% less than the comparable smut-free plants, almost certainly due to the infection.

The data on yield in the $F_1$ crosses are contained in Table 1. The differences ranged from 22 to 74%, with large odds in most cases. The greatest difference occurred when the ear was infected, whereas differences occurring when infection was between the upper ear and the neck ranked second. The smallest difference was when infection was in the lower ear shoot. Pairs of plants with infected shoots between the base and the lower ear and with infected tassels were so few that differences as small as those observed are not significant statistically. Nevertheless, the data showed a consistent tendency toward a lower yield from the smutted plants. A larger difference resulted from smut infection above the upper ear than from infection below it, which is the reverse of the condition in the selfed lines. The smutted plants as a group yielded 50% less than the comparable smut-free plants.

## CONCLUSION

In the $F_1$ crosses, smut-infected plants yielded less than comparable smut-free plants, regardless of the location of the galls. This also was true with the inbred lines, except where the smut occurred in the tassel. In this case, there were only three pairs of comparable plants and the odds are only 3 : 1 that the difference was not due to chance. In 50 paired comparisons in the selfed lines, the smutted plants yielded 39% less than comparable smut-free plants and in 366 paired comparisons in the $F_1$ crosses they yielded 50% less. Odds are sufficiently large so that these differences were not due to chance. These results are comparable to those obtained by some recent investigators (2) who obtained differences ranging from 7 to 94% in selfed lines, using the same method. They are contrary to those obtained by others (1) who were unable to demonstrate any differences in yield, other than those due to barrenness, between smutted

and smut-free plants in the $F_1$ crosses between inbred lines. Here the two plants compared were separated by not more than three hills. Whether or not similar differences would be obtained under other environmental conditions has not been determined. The differences in yield in the $F_1$ crosses probably approximate more nearly the condition in normal corn than do the differences in selfed lines, as the former are more nearly comparable in vigor.

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## NOTE

### MOVEMENT OF FERTILIZER SALTS IN THE SOIL

The fact that fertilizer salts, particularly phosphates, have very little horizontal movement in soils can be easily demonstrated in the field, as was done recently by the writer in a corn field on brown silt loam in central Illinois. On a part of the field, the corn had been fertilized in the hill at the rate of 146 pounds of 4–10–6 fertilizer per acre. When the soil around a standing hill of mature corn was carefully scraped away to a depth of an inch and a half, the fertilizer was found to have been deposited in a mass not much larger in area than that of a silver dollar, and located about 2 or 3 inches from the hill.

Beginning with the center of the fertilizer area, samples of soil in the same plane 3 inches, 6 inches, 9 inches, and 12 inches distant were tested for available phosphorus by the colorimetric method proposed by the University of Illinois, using a hydrochloric acid solution of ammonium molybdate. The soil from the area containing the fertilizer gave a strongly positive test, but all other samples gave a negative test for available phosphorus. Samples of soil taken 2 inches and 3 inches directly below the fertilizer area gave positive tests, indicating some downward movement of phosphorus. Soil from a portion of the field which had received 400 pounds of 20% superphosphate broadcast showed a slightly positive test.

The intensity of the fertilizer application in the hill in this instance was equivalent to a broadcast rate of approximately 32 tons per acre, and yet there was practically no horizontal movement in the soil to a point 3 inches away from the fertilizer as indicated by the phosphorus test.

This phenomenon, which has been observed by others, suggests the importance of a better distribution in the soil of hill-applied fertilizers for maximum efficiency in utilization by the plant. The wonder is that there are not more failures (in the sense of lack of increased yield) than seem to occur with some of the present methods of hill application and distribution in the soil.—OVE F. JENSEN, *National Fertilizer Association, Chicago, Illinois.*

## BOOK REVIEW

### BOTANY: A TEXTBOOK FOR COLLEGE AND UNIVERSITY STUDENTS

*By Wm. J. Robbins and Harold W. Rickett. New York: D. Van Nostrand Co., Inc., XXIV+535 pp., illus. 1929. $3.75.*

This profusely illustrated book is primarily a text book for first year college students in botany. It is rather different from the general run of botanical text books. Besides discussing and explaining biological phenomena, the authors have attempted to show what the scientific method is, how science accumulates data, how theories are advanced, modified, and perhaps retracted. Scientific knowledge is shown to accumulate slowly, to be rarely free from error.

About the first half of the book deals with the structure and the physiology of plants. Facts are presented and ideas gradually developed, with frequent illustrations and examples from plant material. Relationships of one structure to another, or of one process to another are always borne in mind so that the student should gain a fairly detailed, logical conception of the anatomy of plants, and the processes that are going on within them.

Such chapters as "Life and Death" and "The Origin of Life" are interesting in that they draw to the student's mind the contribution of science to these subjects. The limits of the realm of science in these directions are clearly defined.

The latter half of the book covers the range and extent of the plant kingdom. It is not in any sense a dry taxonomic treatise. The larger natural groups in the plant kingdom are described, and their different habits of growth and reproduction related to the discussions in the first part.

A number of pages at the back of the book are devoted to a series of questions grouped according to subject. The questions do not merely ask the student for facts acquired, but are often designed to test his knowledge and comprehension of the subject as a whole.

The numerous illustrations are exceptionally well chosen and arranged. They take various forms, *viz.*, half-tones, sketches, and diagrams. Most are liberally labelled.

In this day of new text books this book is a definite contribution of value. To the student who expects to carry on further studies in botany, it is liable to be an encouragement and an invitation to go forward, while to the one who just desires a general knowledge of botany, whether he is a college student or not, it should undoubtedly be a source of interesting information logically arranged and presented, and yet not in a too elementary way. (L. R. H.)

## AGRONOMIC AFFAIRS

### CONFERENCE ON SOIL AND WATER CONSERVATION

The Proceedings of the first session of the Southwest Conference on Soil and Water Conservation, held at the Texas A. & M. College at College Station, Texas, June 20 and 21, contain a report on the first organized public conference held in the United States to review the losses by erosion and excessive runoff of rainwater from agricultural lands in the less humid parts of the country and to indicate ways and means of reducing these losses. The Proceedings, which contain 64 pages of text and a reconnoissance map of the regional soil erosion areas of the United States, may be obtained from A. D. Jackson, College Station, Texas, Secretary of the Conference.

Agronomists, soil scientists, foresters, agricultural engineers, and extension specialists from several states and from the U. S. Department of Agriculture were in attendance; also representatives of farm

implement manufacturers, fertilizer companies, seed growers association, railroads, etc. A report by the Program Committee outlines a course of procedure which covers the fields of research, education, and extension activities; while state committees were appointed by the several southwestern states participating in the Conference to plan methods of attack within the states. The Conference voted to meet at Oklahoma A. & M. College in 1930.

## THE SECOND INTERNATIONAL CONGRESS OF SOIL SCIENCE

The Second International Congress of Soil Science will open in Leningrad on July 20, 1930, with a six-day session, the Congress then moving to Moscow for a second session of six days. At both centers there will be arranged short trips and exhibits of general interest to soil specialists and agronomists. Following the session in Moscow, there will be a 29-day excursion which will cross all of the soil zones of European Russia, many points of agricultural interest being visited in the course of the trip. In addition special excursions will be arranged, if wanted, to the Mourmansk peninsula for an inspection of peat and forest soils, swamps, railroad colonization, etc.; to Central Asia; to the agricultural show at Minsk; and to other points.

The Executive Committee of the International Society of Soil Science should be advised of intention to attend the Congress not later than February 1, 1930, with a statement of the point from which the visitor will enter Russia, i.e., whether from Berlin, Paris, Warsaw, Riga, etc., in order that the necessary license to enter the country may be provided. The fee for the Congress and the 29-day excursion will be $300 for members of the Board of the International Society and of its permanent committees, while all other members of the Society whose dues are paid up to January, 1930, will pay $350. Those joining the Society after January 1, and all visitors, will pay $450.

All papers intended for the Congress should be forwarded in summarized form, not later than January 1, 1930, either directly to the presidents of the respective permanent Commissions of the International Society of Soil Science or to Dr. A. Yarilov, Chairman of the Executive Committee, Karuninskaja, I, Gosplan, Moscow, U. S. S. R.

## MEETING OF SECTION O IN DES MOINES

The following program has been arranged for a joint session of Section O of the American Association for the Advancement of Science and the American Society of Agronomy at Des Moines, Iowa, on Saturday, December 28.

### SYMPOSIUM ON "RECENT DEVELOPMENTS IN RESEARCH WITH CORN"

*Leader*: John B. Wentz, Iowa State College.

MORNING SESSION

1. Some Problems in the Utilization of Inbred Strains of Corn, R. A. Brink.
2. The Commercial Utilization of Double-Crossed Corn in Minnesota, H. K. Hayes.
3. Practical Aspects of the Newer Methods of Corn Breeding, H. A. Wallace.
4. Genetic Experiments with X-rays in Maize, L. J. Stadler.
5. The Cytology of Certain X-ray Effects in Maize, L. F. Randolph.

AFTERNOON SESSION

6. The Morphology of the Corn Plant, T. A. Kiesselbach.
7. The Corn Plant as a Physiological Mechanism, Charles A. Shull.
8. Some Recent Contributions to Our Understanding of Corn Diseases, I. E. Melhus.
9. The Effect of Environment During Maturation and Seedling Development Upon the Behavior of Inbred and Hybrid Lines of Corn, J. G. Dickson and J. R. Holbert.
10. The Utilization of Corn for Products Other than Food, O. R. Sweeney.

Geneticists interested in agriculture have been invited to meet with Section O and the Society on Saturday morning. On Monday afternoon, December 30, geneticists interested in agriculture are having a joint meeting with the Genetics Section at Ames, and have invited Section O and the American Society of Agronomy to meet with them. The topics to be discussed are as follows:

The Possibility of Obtaining Valuable Data as By-products from Routine Breeding Operations, Jay L. Lush, Texas A. & M. College.
Desirable Experiments which can be Conducted Without much Additional Outlay, E. N. Wentworth, Armour's Livestock Bureau, Chicago.

## NEWS ITEMS

C. B. CROSS, who has been taking graduate work at the University of Nebraska, has accepted a position as Assistant Cerealist at the Oklahoma Agricultural and Mechanical College.

W. H. LEONARD, who has been taking graduate work at the University of Nebraska during the past year, has accepted a position as Assistant Professor of Agronomy at the State Agricultural College of Colorado.

E. N. BRESSMAN, Associate Agronomist, in Charge of Plant Breeding, at the Oregon Station, is completing work for the doctorate at the University of Nebraska. Mr. Bressman is on sabbatical leave for the school year.

T. S. BUIE, Head of the Agronomy Division of Clemson College, S. Car., has resigned to become associated with the Superphosphate Institute with headquarters in Washington, D. C.

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## SOME OUTSTANDING RESULTS OF AGRONOMIC RESEARCH AND THE VALUE OF SUCH CONTRIBUTIONS[1]


M. J. FUNCHESS[2]


Since the organization of the American Society of Agronomy about 21 presidential addresses have been delivered. A survey of these addresses shows that of the 21, only one or two have dealt with definite research results. In his presidential address to the Society on November 16, 1925, past President Warburton opened the address with this paragraph: "The growth of agronomic science since the founding of the American Society of Agronomy in this city, December 31, 1907, has been extremely rapid, and has been attended by an equally rapid growth of agronomic personnel. The title of agronomist was first applied to technical workers in this country in 1900, when three of the staff of the College of Agriculture of the University of Illinois were so designated. Of course, much had been done in the study of soils and crops prior to that date, but agronomy, as agronomy, has existed in the United States only during the past quarter of a century." In the light of this statement and in the light of the fact that most of the presidential addresses in the past have been more or less of the prophetic or lecture type, it seems fitting at this time for your president to look backward over a period of years and deal with some of the outstanding accomplishments of agronomic research.

In preparing this paper, it is obvious that the writer was dependent upon the respective departmental heads to supply the material from the several experiment stations. It is to be regretted that quite a number of groups are not represented through failure to

[1]Presidential address read at the annual meeting of the American Society of Agronomy, at Chicago, Illinois, November 14, 1929.

[2]Director of Experiment Station, Alabama Polytechnic Institute, Auburn, Ala.

supply material for this paper; that which has been supplied is herewith presented in alphabetical order.

The Alabama Experiment Station conducted local fertilizer experiments at more than 200 different places within the state and, from a summary of these experiments, developed a fertilizer program for cotton. More than 20% of the cotton acreage in Alabama is fertilized according to this program. Numerous demonstrations conducted by county agents have shown that the increased profit to the farmer who follows this program is something like $10 per acre. The annual money value, therefore, accruing from this single piece of research amounts to approximately $8,000,000.

More than 1,000,000 pounds of seed of hairy vetch and Austrian winter peas are planted annually. The increased return from this amount of winter legumes is conservatively estimated at $10 per acre, or $500,000 total. This item is not so important in the aggregate, but when one considers that less than 2,000 pounds of this kind of seed were planted in Alabama 10 years ago, and when one realizes that the large amount now planted is due to experimental work conducted by the experiment station, then the item becomes one of material interest.

In the southeastern part of Alabama, much of the land is so thoroughly infested with cotton wilt that the production of cotton is almost impossible with non-resistant varieties. The experiment station developed a strain of cotton that is almost wholly resistant to this disease. The increased value of the crop, due to the use of this strain in the territory where the disease is prevalent, amounts to some $7,500,000 annually.

Important results from the soils laboratory include the discovery that Pasteur-Chamberland filters absorb phosphate, thus making them useless for obtaining soil extracts for phosphate determinations. The collodion sack method was subsequently adapted to this purpose. The barium acetate method for determining replaceable hydrogen in soils is another worthy accomplishment of our laboratory group. In the field of plant nutrition, it has been shown that the minimum phosphate concentration for satisfactory plant growth is much lower than was formerly believed. This result was obtained through the development of a new method of studying the minimum concentration of plant nutrients necessary for satisfactory growth. Finally, mention may be made of the contribution to the knowledge of soil acidity as it is influenced by the use of nitrogenous fertilizers. The money value of such results cannot be estimated.

Outstanding work at the Connecticut Station includes important developments in corn breeding methods which have been of value, not only to Connecticut, but to corn breeders throughout the country. The soils department, through its experiments on tobacco fertilizers, has developed a recommendation that results in an annual saving of at least $100,000 per year in the cost of tobacco fertilizers. Another important development was the discovery of the relationship between soil reaction and the quality of tobacco. Some 30 or 40% of the tobacco crop is influenced by this discovery.

Among the outstanding pieces of work by the agronomy department of the Georgia State College of Agriculture may be mentioned the development of a combination of plants that will make a good pasture on much of the moist lands of the Coastal Plain area. It is estimated that something like 100,000 acres have been seeded to this combination of crops. A conservative estimate places the increased value of this pasture land at $10 per acre. This department also developed an outstanding strain of cotton known as College No. 1 which is now grown on a considerable acreage in Georgia and to a less extent in adjoining cotton states. A new strain of wheat numbered 41–59 and a new strain of rye known as French rye are also noteworthy contributions from the department.

Some of the more important results at the Illinois Station are the development of strains of corn having widely different physical and chemical characteristics, and better adapted strains of wheat and soybeans. The value to the State of Illinois of these items is placed at $1,000,000.

In the selection and testing of seed corn, it is estimated that at least 10% of the 9,000,000 acres of corn in that state have been influenced by this improved practice. At a conservative price for corn the increased production is valued at $3,150,000.

The development of the lime-legume program is considered one of the high spots of the activity of the Illinois Station. As a result of this program, between 700,000 and 800,000 tons of lime are applied to Illinois soils annually. In a 20-year period it is estimated that more than 5,750,000 tons of lime have been used by Illinois farmers. It is very interesting to note that there were only 48,000 acres of sweet clover in 1919. This figure had risen to 697,000 acres in 1928, thus showing a marked parallel between the use of lime and a lime-loving crop.

Work of enormous practical value to farmers at the Indiana Station includes the discovery in the early nineties of the fact that unproductive peaty lands might be made highly productive by

the simple addition of potash fertilizer. The value of this investigation to farmers has been estimated to be worth from $2,000,000 to $5,000,000 annually. In the middle nineties, the formaldehyde treatment for potato scab was discovered. The application of this treatment for potato scab and later for stinking smut of wheat has resulted in savings ranging from $1,000,000 to $4,000,000 per year. Improved varieties of winter wheat and of soybeans have benefited Indiana farmers by at least $500,000 annually during recent years.

Turning now to another corn belt state, it is found that more than 46% of Iowa's 5,000,000 acres of oats in 1924 were planted with varieties originated at the experiment station. In recent years approximately 10% of the Iowa corn acreage is planted with high-yielding strains of seed located through the state corn yield tests. The increased production from this seed is estimated to amount to 1,250,000 bushels of corn annually.

Fifty-nine of the 99 counties in Iowa have been mapped and soil survey reports issued on these counties. The soils department has operated experimental fields on typical soil types in practically all sections of the state. Results from these fields form the basis for the recommendation of the Iowa system of soil management. The importance of drainage has been determined, and it is estimated that about 4,000,000 acres in the Wisconsin drift area have been drained.

The Kansas Station reports that the development of new field cultural methods dealing with the time and manner of preparing land for wheat has increased the Kansas wheat crop to the extent of $12,000,000 per year. The work dealing with crop rotation and the value of lime and fertilizers has markedly influenced the agriculture of a large part of Kansas. The value of the increased returns from the application of the results obtained in experiments of this kind amounts to $13,200,000. The introduction of Kanota oats has resulted in the use of this variety on about 75% of the oats acreage in Kansas. The introduction and development of Kanred wheat has also markedly influenced the crop returns. The introduction and development of these and other crops have resulted in increased production totaling something like $13,000,000 annually.

At the Massachusetts Station some 60 years ago, Stockbridge discovered the need of "complete" fertilizers for Massachusetts soils. It is believed that his discovery and recommendations were the basis of the now extensive practice of the use of "complete" fertilizers, and had much to do with the development of the present

extensive commercial fertilizer industry of this country. Valuable contributions have come from the Massachusetts Station concerning the relative value of various nitrogenous, phosphatic, and potassic fertilizer materials. Some of the outstanding contributions from this fertilizer work are:

1. The continued use of fertilizer materials containing only one of the critical plant food elements impairs the productivity of glaciated soils.

2. The continued use of ammonium sulfate, unaccompanied by the use of lime, produces a toxic, acid soil condition, inimical to optimum plant growth.

3. Crop yields can be maintained over a long period by the use of commercial fertilizer alone.

From Michigan comes the report that the alfalfa acreage in that state has increased from 74,000 acres in 1919 to 518,000 acres in 1928 as a result of tests to determine the best type of alfalfa. This one piece of work has returned to the state increased crops with values amounting to something like $10,000,000 per year. This station has developed or introduced a number of better adapted varieties such as Red Rock wheat, Rosen rye, Wolverine oats, and a number of others. These varieties are used annually on more than 3,000,000 acres of land and are adding annually from $4,000,000 to $6,000,000 to the income of Michigan farmers.

It is reported from Minnesota that the most important work of the division of agronomy and plant genetics is the production and introduction of new varieties of small grains. The potential increase from the use of such strains as Marquillo and Minturki wheat, Gopher and Anthony oats, and other improved crops total $18,290,000 annually. These improved grain crops are more rust resistant, or more winter hardy, or higher yielders than the common kinds of crops formerly used.

The field crops department of Missouri reports that through the efforts of that department the corn varieties grown in Missouri have been standardized to the extent that there are only three or four kinds of corn now being grown in that state. Similar results have been obtained with wheat. The leading variety of wheat in Missouri was developed at the experiment station. An improved strain of Fulghum oats has been promoted and is now the leading variety of that crop. The introduction and promotion of soybeans began 12 years ago, and this effort has met with such satisfactory results that soybeans are now one of the major crops in Missouri.

The department of soils at Missouri is conducting one of the most interesting experiments in soil erosion that has ever been initiated

in this country. As a result of the determination of erosion losses, it has been found that 7 inches of plowed soil may be entirely removed in 24 years if the land is plowed shallow and fallowed. This same result will be obtained in 57 years under continuous cropping to corn. These outstanding results have stimulated similar studies at a number of other places in the states. Research work dealing with the heavy layer of clay that underlies vast areas in Missouri has developed a clearer conception regarding the nature of acidity of the colloidal material in such soils. Flocculation studies made with the natural clay and the pure clay systems show how important the use of purified systems are if an understanding of the fundamental processes involved is to be obtained. It is believed that a study of the physical properties of these purer clays has laid an excellent foundation for the understanding of some of the problems of soil structure. This work probably marks one of the notable contributions to our knowledge of the nature of the colloidal material in soils.

It is estimated that 60% of the 3,500,000 acres of winter wheat in Nebraska are now planted to an improved selection known as Nebraska No. 60, and an additional 15% of the acreage to Kanred wheat which the Nebraska department adopted from Kansas. The increased yield resulting from these two strains amounts to 3,937,000 bushels annually. Nebraska No. 21 oats and several other early varieties that have been introduced are estimated to have added 3,500,000 bushels to the oat crop of that state. Fully 70% of the 9,000,000 acres of corn in Nebraska is planted with seed of a better adapted type due to the activities of the agronomist. It is believed that these better adapted strains are adding annually 16,875,000 bushels of corn to the Nebraska crop. The campaign for sweet clover has resulted in an increase in acreage from 30,000 in 1920 to approximately 500,000 acres in 1927. On thin soils the grain yields are frequently doubled by the use of sweet clover in a soil improvement program.

From New Jersey comes the suggestion that studies of the availability of nitrogenous fertilizers are among the most important projects in progress. These studies have developed the fact that, in general, inorganic forms of nitrogen have given somewhat better results than organic forms. Another important study dealt with the comparative value of magnesian and non-magnesian limestone. These two forms of lime have given very similar results when used in approximately equal amounts. Cooperative fertilizer experiments with potatoes have been used as a basis for establishing a good fertilizer practice in the production of potatoes in New Jersey.

Corn studies have developed the fact that most of the well-known standard varieties are not adapted to New Jersey conditions. Six varieties have been found to be well adapted and these are being recommended for use in that state. It is estimated that the corn crop of New Jersey may be increased 10% as a result of this work. Three varieties of wheat have been found to be adapted and it is estimated that the use of these would bring an increase in crop value amounting to $200,000, annually. Alfalfa is being substituted for timothy and clover and is giving an increase in returns to the extent of about $1,000,000 annually.

Some of the most significant contributions from New York are (1) transformations of nitrogenous compounds in soil; (2) lysimeter studies on income and outgo of plant nutrients from soils; and (3) methods of experimentation with particular reference to devices for reducing the experimental error in experiments involving soils and plants. Under the first subject it has been shown that growing plants may cause the disappearance of nitrates from the soil in some way other than by absorption by the plant. An explanation of this result has been attempted, and it is believed that good progress has been made in this direction. The injurious effect of sod on the growth of young fruit trees has been shown to be due to the interference with the accumulation of nitrate nitrogen. It has been stated that trees cannot compete successfully with the nitrate-consuming organisms when they are supplied with certain kinds of material by the grass roots in the sod.

The lysimeter studies have made it possible for the first time to make a clear-cut distinction between the loss of nitrogen from soil in drainage water, and the loss due to some cause not yet discovered.

Under the third heading good progress has been made in devising apparatus for conducting experiments in plant production under controlled conditions. Perhaps the most useful invention is the artificial field plats or frames which are intended for reducing experimental error in field experiments. Since the publication of the results of the use of such frames, a number of experiment stations have made use of this idea, and are now able to conduct field experiments on land that was formerly useless for this purpose.

From among the many accomplishments at the North Carolina Station mention may be made of the following. The best proportions and quantities of fertilizer mixtures to be used for different crops grown on different soil types have been determined by field experiments. Along this same line the best sources of commercial phosphoric acid, potash, ammonia, and lime for different crops and soils

have been established by field experiments. There has been worked out the most effective method and time of application of fertilizer materials for different crops on different types of soils. Some of the best systems of crop rotations have been determined. Field crop studies have developed the soil type adaptation of such crops as alfalfa, red clover, crimson clover, Japan clover, sugar beets, wheat, and soybeans. Among the studies on tobacco production, one of the most outstanding is the discovery of the effect of available magnesium on this important crop. It is found that excessive liming of the soil may injure certain crops like corn, soybeans, and oats. This over-liming may be remedied by application of large amounts of potash. Two standard varieties of cotton have been adopted for North Carolina, and these largely replace the many unimproved varieties formerly grown.

The agronomy department of North Dakota developed Ceres wheat. In 1929 it is estimated that 300,000 acres of wheat were planted to this strain, and that there may be from 5% to 10% increase in yield due to the use of this better kind of wheat. Linota flax, a selection from common flax is estimated to occupy from 20% to 25% of the acreage and to yield at least 10% more flax than the common varieties now grown. Dakold rye occupies about two-thirds of the rye acreage, and is estimated to yield from 20% to 25% more than less hardy kinds. A notable contribution from the botany department of this station which is considered of much agronomic value is the selection of disease-resistant flax. It is believed that flax would have disappeared from the state of North Dakota but for the introduction of disease-resistant strains.

I quote directly from the Ohio report four paragraphs setting forth the work of that station.

". . . . Ohio farmers are now using annually around 225,000 tons of ground limestone and other liming materials. Based upon the experimental returns from liming at 15 points in the state, the returns from the use of this amount of lime are about \$2,550,000 per year at a money cost of about \$1,020,000, leaving a gross balance of \$1,530,000 per year.

"In the matter of fertilizers, according to the recent survey of the National Fertilizer Association, Ohio farmers used in 1927, 312,700 tons of fertilizer. The estimated returns were \$30,272,000 with an estimated cash expenditure of \$8,810,000, leaving a gross balance of \$21,462,000 for the year.

"That farmers of the state are highly responsive to recommendations of the College and Station is indicated by certain changes in fertilizer usage during recent years. In 1922, we began a campaign for standardization on a limited list of higher analysis fertilizers. At that time one-third of all mixed fertilizers sold in the state carried

less than 13% total plant food constituents. Since that time these low-grade mixtures have practically disappeared, while in the same time the amount of nitrogen used in mixed goods has doubled and the amount of potash has trebled. Also, beginning 4 years ago, the recommendations of the College and Station for fertilizing corn were changed from straight broadcast application to include hill and row treatment. A recent survey indicates that three-fourths of the farmers of the state are now following these newer recommendations.

"In the development of new varieties of crops it is perhaps easier to arrive at a definite money value of an agronomic accomplishment. For example, 60% of our Ohio wheat acreage is now seeded to either of two varieties Trumbull and Fulhio, developed by the Station through the process of head selection. Several thousand threshermen's records indicate that the yields obtained from these improved varieties exceed that of the other commonly grown sorts by more than 3 bushels per acre. With a total acreage of around 2,000,000 acres of wheat per year, this means about 1,200,000 acres of the improved wheats and an annual gain of 3,600,000 bushels worth around $4,500,000 to the farmers of the state."

Reports from the Pennsylvania Station state that the leading strain of wheat in that state, known as Pennsylvania 44, resulted from the breeding work of the agronomy department. It is estimated that more than one-third of the wheat acreage of the state is planted to this variety. It is estimated that the value of this one improved variety to the wheat growers of this state would be more than the money spent in experimental and research work by the experiment station since its origin. Two outstanding varieties of oats, known as Keystone and Patterson, which were developed by the station, are in much demand in all parts of the state and are better than common varieties in both yield and quality. A strain of timothy developed by the department yields one-half ton per acre more than is produced by commercial seed.

The soil fertility plats at this station are among the best known plats in this country. This is the 48th year of the work, and it is reported that there has been no interruption and no crop failure during this long period of time. Many important lessons as to the character and amount of fertilizer, the amount of barnyard manure, and the effect of lime on soils have been given to the agronomists of the country from these plats.

It is very probable that the discovery of the possible acidity of upland soils should be credited to the Rhode Island Experiment Station. At any rate, the first and most extensive study of soil acidity of upland soils was made by that station. It is also probably true that the most extensive classification of plants with regard to their tolerance of acidity was made there. Following these acidity studies,

tests of various liming materials are mentioned among the important pieces of work of the station. The comparative value of various forms of phosphorus, potash, and nitrogen has been a subject of considerable experimentation. Studies dealing with the effect of certain crops on succeeding crops are the most comprehensive in this country. Recent studies have shown that there is a possible deficiency of manganese in certain soils when planted to certain crops. It is proper to state that some of these early studies at the Rhode Island Station have been of much benefit in other states in addition to their value to the state of Rhode Island. Certainly, their early studies on acidity stimulated much study of this same problem in other states where formerly soil acidity was not considered to be a problem.

The South Carolina Station reports that improved fertilizer practices resulting from the work of the agronomy department have produced an increased yield of crops valued at $1,000,000. The correct spacing of cotton plants under boll weevil conditions has produced another increase in the yield of cotton estimated to be worth $800,000. The introduction and development of new varieties of farm crops is worth annually $3,000,000, while the development and introduction of new field cultural methods have increased the returns of South Carolina farmers by $2,500,000.

Moving now from the center of the Old South to the Far North, it is shown by the department of agronomy of South Dakota that the introduction and development of new varieties of wheat may account for an increase of 3.3 bushels per acre on each acre devoted to wheat in that state. Likewise, the introduction of better varieties of corn may increase crop returns of South Dakota farmers by some 10.2 bushels per acre. Barley yields may be increased 6.1 bushels. Alfalfa may be increased by 0.4 ton. Potato yields may be increased 25 bushels by application of the results obtained by this group. It is estimated that the potential value of these increases may amount to approximately $65,000,000 in this one state.

In 1911, the Tennessee Experiment Station first included in its corn variety trial a variety known as Neal's Paymaster. This variety was found to be of outstanding merit and was introduced extensively in 1916. It is estimated that at least 1,000,000 acres of the Tennessee corn crop are now planted to this variety, and that the increased crop resulting from its use is worth nearly $3,000,000 annually. Fertilizer experiments with cotton have led to a definite recommendation as to the kind and amount of fertilizer that should be applied to this crop in the cotton-producing area. A considerable part of the

increased cotton crop in Tennessee may be attributed to the practice recommended by the agronomy department. It has also been shown that the cotton area may be divided into two parts, one of which needs little or no phosphate, while on the other, phosphate was found to be of great practical importance. The recommendation that the use of phosphate be curtailed in one of these areas has resulted in saving at least $100,000 on the annual fertilizer bill. The value of lime for Tennessee farmers has been thoroughly determined and in some counties its importance has been generally recognized by farmers. The Tennessee Station may be justly proud of its development of a strain of lespedeza that is much more valuable than the common forms over a large area of the South. The demand for seed of this strain usually exceeds the supply. This strain produces about 25% more hay than the common lespedeza from which it originated. Another accomplishment of much importance was the discovery of a disease-resistant red clover. The use of this strain of clover makes possible a crop on land that formerly failed to grow red clover at all. Efforts are now being made to have seed of this disease-resistant strain produced in quantities.

One of the important results of the work of the West Virginia Station has been the discovery of the marked response of the farm lands of that state to phosphates and lime. It is estimated that the increased use of fertilizer, due to the work of the agronomists, has returned an annual profit to West Virginia farmers of something like $1,000,000. The introduction and dissemination of soybean seed in the state have resulted in a large increase in the acreage devoted to this important crop. In cooperation with the United States Department of Agriculture the agronomy department has shown that one of the main causes of red clover failure was the use of unadapted seed.

Grain breeding work was started by the agronomy department at the Wisconsin Experiment Station in 1897. Later an organization was formed to grow and distribute the improved seeds produced by this department. Through the efforts of the department and this seed growers' organization, practically all of the corn crop in Wisconsin is planted with seed from five varieties developed and introduced by the department. Wisconsin pedigreed barley, in tests made by 1,500 members of the experiment association, showed a yield of more than 10 bushels per acre better than other common varieties. It is estimated that 98% of all barley grown in Wisconsin came from this improved strain. Improved strains of oats, such as the Wisconsin Pedigreed No. 7, account for practically 90% of the entire oat crop

grown in the state. Three-fourths of the spring wheat planted in the state is of the Progress variety. The production of hemp has been pushed during the past 18 years, and these efforts have been rewarded to the extent that, now, Wisconsin is the leading hemp fiber state of America. In recent years the department of agronomy has made a strenuous effort to increase the acreage devoted to alfalfa. This work has resulted in a marked increase in the acreage devoted to this crop in recent years.

Finally, much valuable work of an agronomic nature has been done by the U. S. Department of Agriculture. Space will not permit a full presentation of the accomplishments of this Department, but a few of the most important items must be mentioned. Twenty-five years ago the soybean was practically unknown to the farmers of this country, and only a few varieties were known to the agronomist. Hundreds of varieties have been introduced by the Department, and tested as to adaptation in the several agricultural regions of the states. The stimulus given to soybean studies in the several states by the Department has resulted in the development of a crop of major importance to American agriculture.

During the last 20 years Sudan grass has become a very important crop throughout a good part of the United States. The value of this hay crop has been placed at $15,000,000 annually. This very valuable crop was unknown here previous to 1909, and its introduction and dissemination by the Department might well be considered among the valuable contributions. Other lines of work that have markedly influenced the agriculture of great areas are the introduction of better adapted and higher yielding varieties of alfalfa, and disease-resistant, cold-hardy strains of red clover. Ladino clover has been successfully established in certain sections of the West where it has a carrying capacity as pasture, exceeding fron two to four times that of any other pasture plant.

The introduction of sorghum has done much to stabilize agriculture in the semi-arid regions. This crop from South Africa provided the wheat farmer with a dependable feed crop, both grain and forage, without which it would have been extremely difficult for him to support any livestock other than his work animals. This crop is well adapted to a large area of our country that has too light a rainfall to produce satisfactory crops of corn.

Introduction and developmental work of much value to various agricultural areas of the country has been done with such plants as Natal grass, Rhodes grass, Napier grass, Bahia grass, and others. Likewise, there has been much valuable work contributed in connec-

tion with leguminous crops, such as velvet beans, winter field peas, cowpeas, vetches, and crotolaria.

Space does not permit a further presentation of materials of this kind. It is sufficient to close with the observation that agronomic work has abundantly justified its existence in connection with American agriculture. Naturally, the agronomist believes that his is the most important phase of agriculture. I take the liberty to quote from a recent letter by an agronomist of one of our experiment stations. He says, ". . . . It seems to me that the crux of the difference between success and failure in the business of farming may well lie and often does lie within the attention which the farmer himself gives to the application of agronomic methods. It is my estimate that the soundest economics in agriculture today is improved agronomy and conversely that more farmers in the United States have 'gone broke' because they were hopeless agronomists than for any other reason. . . . ."

It appears to be true, then, that we have made much progress during the last 25 years, so that today the output of American agriculture is being maintained, or even increased, by a declining number of workers. This is as it should be. But it is not time for us to rest on our oars. Even though we sometimes hear the false teaching that our production problems have been solved, and that our troubles are due mainly to poor marketing and distribution practices, the wise agronomist will continue his efforts to discover methods to make each acre and each hour of man labor return an ever increasing amount of crops. Let us never forget that our problem may be stated as one of economical production, and that high yields per acre economically obtained form the basis of low cost production. As we accomplish this result, we build a firmer basis for American agriculture, and earn for ourselves the satisfaction of having been of some service to all mankind.

# THE NITROGEN BALANCE IN CULTIVATED SEMI-ARID WESTERN KANSAS SOILS[1]

P. L. Gainey, M. C. Sewell, and W. L. Latshaw[2]

## INTRODUCTION

For a number of years, there has been a growing belief among students of soil fertility in semi-arid regions that there may be a radical difference in the nitrogen balance of cultivated soils under humid and semi-arid conditions; a difference that cannot be accounted for solely on a basis of nitrogen removed in the crop, in drainage, or by other means. It is a well-established fact that under humid conditions the continuous growth of non-leguminous crops almost invariably brings about a very rapid depletion in soil nitrogen. The problem of maintaining an adequate supply of nitrogen for profitable productivity has long been the outstanding problem in soil fertility under such conditions.

However, as pointed out by Wilsdon and Ali (11),[3] some of the dry-land cultivated soils of semi-arid India have been under continuous grain culture for centuries, during which time very little, if any, nitrogenous manures have been applied. Yet these soils, probably originally poor in nitrogen, will today produce an abundant grain harvest provided there is sufficient moisture available.

The question of the nitrogen balance of dry-land agricultural soils is a vital one over a large part of the semi-arid West. Large areas of such soils are grown continuously to grain crops and, according to Jones and Yates (3), "No cover or green manure crop appears at this time to be even remotely practicable for vast areas of dry-farming lands that receive the smaller amount of rainfall." However, if the well-established nitrogen-depleting characteristic of continuous grain growing under humid conditions is equally applicable here, where the nitrogen content of the soil is exceptionally low to begin with, it is only a matter of a few years before nitrogen and not moisture must inevitably become the limiting factor in crop production.

[1]Contribution No. 117 from the Department of Bacteriology, No. 183 from the Department of Agronomy, and No. 147 from the Department of Chemistry of the Kansas Agricultural Experiment Station, Manhattan, Kan. Received for publication May 4, 1929.

[2]Soil Bacteriologist, Associate Professor of Soils, and Associate Chemist, respectively. Grateful acknowledgment is hereby made to Dr. C. O. Swanson, Professor of Milling Industry, formerly Soil Chemist, whose foresight in initiating this work in 1916 made possible this report.

[3]Reference by number is to "Literature Cited," p. 1153.

Fortunately, the loss of nitrogen through drainage is almost a negligible factor under semi-arid conditions. That very large losses of nitrogen may take place in some other, as yet little understood, manner is indicated in data submitted by Sievers and Holtz (4) and in that reported in Tables 1 and 2 of this paper. It is quite evident, then, that reliance cannot be placed upon the low nitrogen removed in crops and drainage as a guarantee of a prolonged nitrogen-supplying ability of semi-arid soils.

Furthermore, Sievers and Holtz (6) have reported remarkable increases in yield of wheat following the application of nitrogen to soils of eastern Washington where ordinarily moisture is regarded as the limiting factor in crop production.

In support of the views expressed in the opening paragraph attention should be called to data secured from a few isolated, though admittedly insufficiently controlled experiments, previously reported.

In an effort to find out the effect of dry-land cultivation upon the nitrogen content of eastern Oregon soils, Bradley (1) made nitrogen determinations upon a few cultivated and adjacent virgin soils. The rainfall of this region is 6 to 15 inches and Bradley's data, meagre though they are, indicate practically no loss in nitrogen during 25 years cultivation.

Stewart (7) reported comparisons of the nitrogen content of virgin and cultivated soils from 10 different locations in the Cache Valley dry-farming area of Utah. The rainfall in the dry-farming areas of Utah is 12 to 15 inches, the average at the Nephi substation being 13.5 inches. The cultivated soils examined had been cropped 8 to 41 years, and on the average contained practically as much nitrogen as the adjacent virgin soil.

Stewart suggests three possible explanations to account for the failure of the surface soil to show a decrease in nitrogen under cultivation, *viz.*, (a) the translocation of nitrogen from lower levels to the surface; (b) the free fixation of nitrogen; and (c) the utilization of nitrogen by the wheat plant primarily in lower strata, with the subsequent deposition of the nitrogen contained in the straw in the surface foot.

Thatcher (10) reported nine comparisons between the nitrogen content of cultivated and non-cultivated soils of the dry-land area of eastern Washington, where the rainfall varies from 12 to 23 inches. Some of the cultivated soils showed no indication of decreases in nitrogen when compared with similar virgin soils.

Stewart and Hurst (8) reported comparisons of the nitrogen content of virgin and cultivated soil from three other locations in the

dry farming area of Utah. At Nephi, 11 virgin soils gave an average of 0.105% nitrogen in the surface foot, while 12 cultivated samples gave 0.103%. At Bear River, the average nitrogen content of the surface foot of seven virgin samples was 0.105%, while seven cultivated samples gave 0.101%. Fifteen cultivated samples similarly collected at Salt Lake averaged 0.1141%, while three virgin samples averaged only 0.0763%. Again the data indicated no perceptible losses in Utah dry-land soils after 10 or more years of cultivation.

Swanson and Latshaw (9) made a number of determinations of the nitrogen content of virgin and cultivated soils of Kansas. For comparison they divided the samples into three groups, depending upon the rainfall of the section of the state from which the samples came. The cultivated samples from the "humid" section, i.e., rainfall in excess of 30 inches, showed an average loss of 32.13% nitrogen. The comparative figures for the "sub-humid," i.e., rainfall 22 to 30 inches, and "semi-arid," i.e., rainfall less than 22 inches, sections were, respectively, 23.75 and 20.48%. Two comparisions where the rainfall was less than 20 inches showed no perceptible decrease in the nitrogen content following 20 or 30 years of grain farming. These data indicate that as the rainfall decreases the losses of nitrogen under grain cultivation decrease.

While it is wished to confine this discussion to the semi-arid soils of the United States, attention might again be called to the data reported by Wilsdon and Ali (11) secured upon India soils with a rainfall of 15 inches or less. Very large increases in the nitrogen content of dry-land cultivated soils are indicated in some of their data.

There are, of course, numerous instances on record where the nitrogen losses under cultivation in semi-arid regions are comparable to those under humid conditions. However, the recurrence of instances in which losses are slight or *nil*, indicates the existence of some nitrogen-compensating factor. Free fixation has repeatedly been suggested as the factor. Stewart (7), for example, states that *Azotobacter* can be isolated with exceptional ease from Cache Valley dry-land farming soils.

Sievers and Holtz (5), in spite of large losses of nitrogen noted by them in many instances, say, "It is possible that in the extremely arid regions where nitrogen losses through cropping are light, there may be sufficient free fixation of nitrogen to provide for the maintenance or even increase the soil organic matter. In the more humid portions of the area the loss of nitrogen through cropping is heavier and free fixation cannot be relied upon to maintain the supply."

Attention might also be called to the point of view held by the Colorado Agricultural Experiment Station, as expressed in numerous publications, relative to the origin of the nitrogen in the so-called "niter spots." These areas, containing excessive quantities of nitrate nitrogen, occur frequently in semi-arid regions when the moisture and other conditions become favorable, and the Colorado Station maintains that the nitrogen is fixed by free-living bacteria and subsequently undergoes nitrification.

In the experiments referred to in the foregoing pages with the exception of the work of Wilsdon and Ali, the methods of arriving at the influence of cropping upon the nitrogen content of the soil have been more or less indirect. In no instance has the nitrogen content of a particular soil been determined prior and subsequent to a period of cultivation. Sievers and Holtz (4), and likewise Jones and Yates (3), compared the nitrogen content in soils subjected to different methods of cropping for 18 and 11 years, respectively, but unfortunately no nitrogen determinations were made upon the soil at the beginning of their experiments. Any conclusions drawn from data secured by comparing the nitrogen content of cultivated with virgin soils must be based upon the assumption that the original nitrogen content of the two or more soils compared was identical. Such an assumption is open to serious criticism, especially unless large numbers of comparisons vary qualitatively alike.

## EXPERIMENTAL METHODS

Realizing the need for more definite information relative to the nitrogen balance in western Kansas soils the Kansas Agricultural Experiment Station began experiments in 1916 at three substations, with the object of definitely determining to what extent various cropping systems in semi-arid western Kansas brought about a depletion in the soil's store of nitrogen.

These experiments were located at Hays with a precipitation of 23 inches, at Garden City with a precipitation of 19.3 inches, and at Colby with a precipitation of 18.3 inches. At that time a number of variously treated plats at each substation was carefully sampled to a depth of 6 2/3 inches. Some of these same plats were again sampled in 1927 and 1928. The treatments, together with the nitrogen content of the soil at the two samplings, are recorded in Tables 1, 2, and 3.

The plats upon which these experiments were conducted were 1/10 acre in size. In 1916, the nitrogen determinations were made upon a composite of six borings from each plat. The nitrogen de-

terminations made in 1927 and 1928 were upon a composite of 12 borings from each plat.

It is unfortunate that sufficient numbers of similarly treated plats have not been analyzed to admit of the application of statistical methods in the analysis of the data. However, where duplicate treatments have been compared, the changes in the nitrogen content, as indicated by the data, have been either very slight or, if marked, have been of the same order, i.e., have shown a marked decrease or marked increase in nitrogen content.

At Hays, for example, plats A, C, and D of rotation 57 (triplicates); plats A, B, C, and D (quadruplicates) of the M. C. milo series; C and D (duplicates) of the M. C. kafir series; and A and B (duplicates) of series 556, all show marked losses; whereas the M. C. wheat plats, C and D (duplicates), and the M. C. barley plats, C and D (duplicates), show but slight losses. Similarly, at Garden City plats C and D (duplicates) of the M. C. wheat series both show appreciable gains; plat C of rotation 405 shows a slight gain, while its duplicate B registered a slight loss. All other duplicated plats at Garden City show slight losses.

There are a few instances where replicate plats show qualitatively similar results but quantitatively very poor agreement. Among these may be noted plats A and C rotation 156, A and D rotation 151, and A and D rotation 152 at Colby; also plats A and B rotation 560, A and B rotation 559, and A and B rotation 555 at Hays. The absence of agreement in such instances can be at least partially explained on a basis of the nitrogen content of the soil of the respective plats in 1916. As will be pointed out later, there is a good correlation between the nitrogen content in 1916 and the subsequent changes in the nitrogen content. The higher the nitrogen content the greater the loss. In the examples just cited the difference in the nitrogen content of duplicate plats amounts, in one instance, to 0.031%, or an actual nitrogen content of 26+% more in one than in the other, and the differences were appreciable in practically all examples where a significant difference in the change in nitrogen content of replicate plats is evident.

Another angle from which the accuracy of the analytical methods involved may be checked is in comparisons of analyses made on the same plats in 1927 and 1928. There were 14 plats sampled and analyzed both years and while these are, of course, not exact duplications, nevertheless if it be assumed that any changes during the year 1927–28 were of the same order as the preceding 11 years, a perfectly justifiable assumption, then a correction can be made

that will place the two analyses upon the same basis. This has been done in all the tables by increasing by one-eleventh the losses or gains evident from the 1927 analyses. Such a procedure would certainly tend to magnify rather than minimize any error present, thereby increasing rather than decreasing any analytical error based upon such comparisons.

Upon comparing the data thus secured from the 14 theoretical duplicate analyses, it is found that the maximum difference observed was only 247 pounds of nitrogen per acre. It would then appear that changes in the nitrogen content of a magnitude of less than 250 pounds are probably not significant, while if differences exceed this value very much, they probably represent actual differences. These facts, while inconclusive, indicate that where the data point toward marked differences in the nitrogen balance between differently treated plats, or even between similarly treated plats at different substations, such differences are significant.

## PRESENTATION OF DATA

Realizing fully the limited interpretative value of data that cannot be submitted to statistical treatment, and also the large experimental error resident in a limited number of nitrogen determinations upon soil, it is believed, nevertheless, that the data submitted in Tables 1, 2, and 3 indicate certain tendencies in the nitrogen balance of semi-arid dry-land cultivated soils.

Before any effort is made to compare the effect of various treatments upon the nitrogen balance of the soil, it is wished to call attention to the rearrangement of certain of these data in Table 4. As previously suggested, there are several instances in which duplicate plats agreeing qualitatively have shown wide differences quantitatively. In addition to the specific instances already cited, one other case is worthy of mention, namely, a comparison between the M. C. winter wheat and M. C. spring wheat series at Colby. While not exact duplicates, the treatments in the two series have been so similar as to lead one to expect somewhat similar effects upon soil nitrogen changes, nevertheless, very marked differences are evident, the M. C. winter wheat plats showing a loss of more than 400 pounds more than the negligible losses that have taken place in the M. C. spring wheat plats.

True, the winter wheat has slightly outyielded the spring wheat, but the differences in nitrogen removed by the growing crop could not account for more than 20 pounds. This marked difference was difficult to understand until the correlation between the nitrogen

TABLE 1.—*Changes in the nitrogen content of soil subjected to different treatments during a 12-year period at Hays, Kansas.*

| Plat No. | Treatment | Nitrogen in soil 1916 | Nitrogen in soil 1927 1928 | Nitrogen lost in 12 years | |
|---|---|---|---|---|---|
| | | % | % | % | *pounds* |
| 552B | Winter wheat, kafir, fallow | 0.167 | 0.124* | 28.1 | 938 |
| 553A | Winter wheat, kafir, fallow | 0.162 | 0.134 | 17.3 | 560 |
| 554A | Winter wheat, kafir, fallow, 2½ tons straw | 0.162 | 0.130 | 19.6 | 640 |
| 555A | Winter wheat, kafir, fallow, 3 tons manure on wheat | 0.170 | 0.152 | 10.6 | 360 |
| 555B | Winter wheat, kafir, fallow, 3 tons manure on wheat | 0.179 | 0.141* | 23.2 | 829 |
| 556A | Winter wheat, kafir, fallow, 6 tons manure on wheat | 0.179 | 0.149 | 16.8 | 600 |
| 556B | Winter wheat, kafir, fallow, 6 tons manure on wheat | 0.172 | 0.137* | 22.2 | 764 |
| 559A | Winter wheat, kafir, fallow, 9 tons manure on kafir seed-bed | 0.160 | 0.151 | 5.6 | 180 |
| 559B | Winter wheat, kafir, fallow, 9 tons manure on kafir seed-bed | 0.179 | 0.148* | 18.9 | 676 |
| 560A | Winter wheat, kafir, fallow, 12 tons manure on kafir seed-bed | 0.167 | 0.160 | 4.2 | 140 |
| 560B | Winter wheat, kafir, fallow, 12 tons manure on kafir seed-bed | 0.188 | 0.157* | 18.0 | 676 |
| 53A | Winter wheat, rye green manure, barley, corn | 0.150 | 0.142 | 5.3 | 160 |
| 53D | Winter wheat, rye green manure, barley, corn | 0.162 | 0.152* | 6.7 | 218 |
| 54A | Winter wheat, cowpeas green manure, barley, corn | 0.143 | 0.133 | 7.0 | 200 |
| 54D | Winter wheat, cowpeas green manure, barley, corn | 0.143 | 0.134* | 6.9 | 196 |
| 55A | Winter wheat, kafir, barley, rye green manure | 0.173 | 0.151 | 12.7 | 440 |
| 56A | Winter wheat, kafir, barley, cowpeas green manure | 0.160 | 0.144 | 10.0 | 320 |
| 56B | Winter wheat, kafir, barley, cowpeas green manure | 0.150 | 0.134* | 11.6 | 349 |
| 56D | Winter wheat, kafir, barley, cowpeas green manure | 0.160 | 0.146* | 9.6 | 305 |
| 57A | Winter wheat, corn, barley, fallow | 0.142 | 0.123 | 13.4 | 380 |
| 57C | Winter wheat, corn, barley, fallow | 0.147 | 0.126* | 15.6 | 458 |
| 57D | Winter wheat, corn, barley, fallow | 0.144 | 0.127* | 12.8 | 371 |
| MCW wheat A | Winter wheat (continuous), late fall plowed | 0.170 | 0.161 | 5.3 | 180 |
| MCW wheat B | Winter wheat (continuous), early fall plowed | 0.155 | 0.149* | 4.2 | 131 |
| MCW wheat E | Winter wheat (continuous), fall plowed, subsoiled 3rd year | 0.152 | 0.135 | 11.2 | 340 |
| MCW wheat F | Winter wheat (continuous), fall listed | 0.161 | 0.152* | 6.1 | 196 |
| MCW wheat F | Winter wheat (continuous), fall listed | 0.161 | 0.139 | 13.7 | 440 |
| 591A | Winter wheat, not plowed, stubbled in continuously | 0.168 | 0.150* | 11.7 | 393 |
| MCW wheat C | Winter wheat, fallow | 0.135 | 0.136* | +0.8 | +22 |
| MCW wheat C | Winter wheat, fallow | 0.135 | 0.131 | 3.0 | 80 |

| | | | | | | |
|---|---|---|---|---|---|---|
| MCW | wheat D | Winter wheat, fallow | 0.155 | 0.148* | 4.9 | 153 |
| MFW | wheat M | Winter wheat, fallow, early summer plowed | 0.155 | 0.136 | 12.3 | 380 |
| 570A | | Winter wheat, fallow, three years | 0.169 | 0.136 | 19.5 | 660 |
| 570B | | Winter wheat, fallow, three years | 0.166 | 0.125* | 26.9 | 895 |
| 570C | | Winter wheat, fallow, three years | 0.166 | 0.142* | 15.8 | 524 |
| 570D | | Winter wheat, fallow, three years | 0.169 | 0.137* | 20.7 | 698 |
| MC | barley B | Barley (continuous), fall plowed | 0.132 | 0.131 | 0.8 | 20 |
| MC | barley C | Barley, fallow | 0.113 | 0.111 | 1.8 | 40 |
| MC | barley D | Barley, fallow | 0.128 | 0.121 | 5.5 | 140 |
| MC | kafir B | Kafir (continuous), fall plowed | 0.138 | 0.125* | 10.3 | 284 |
| MC | kafir E | Kafir (continuous), fall listed | 0.147 | 0.119 | 19.0 | 560 |
| MC | kafir C | Kafir, fallow, spring plowed | 0.138 | 0.109* | 22.9 | 633 |
| MC | kafir C | Kafir, fallow, spring plowed | 0.138 | 0.094 | 31.9 | 880 |
| MC | kafir D | Kafir, fallow, spring plowed | 0.145 | 0.121* | 18.1 | 524 |
| MC | milo B | Milo (continuous), fall plowed | 0.145 | 0.127* | 13.5 | 393 |
| MC | milo E | Milo (continuous), fall plowed, subsoiled 3rd year | 0.153 | 0.113 | 26.1 | 800 |
| MC | milo C | Milo, fallow, spring plowed | 0.151 | 0.111* | 28.9 | 873 |
| MC | milo C | Milo, fallow, spring plowed | 0.151 | 0.101 | 33.1 | 1,000 |
| MC | milo D | Milo, fallow, spring plowed | 0.148 | 0.117* | 22.8 | 676 |

*1927 analyses.

**TABLE 2.**—*Changes in the nitrogen content of soil subjected to different treatments during a period of 12 years at Colby, Kansas.*

| Plat No. | Treatment | Nitrogen in soil 1916 | Nitrogen in soil 1917 1918 | Nitrogen lost in 12 years | |
|---|---|---|---|---|---|
| | | % | % | % | *pounds* |
| 552A | Winter wheat, milo, fallow | 0.121 | 0.098 | 18.3 | 440 |
| 554A | Winter wheat, milo, fallow, 2½ tons straw on wheat | 0.119 | 0.103 | 13.4 | 320 |
| 555A | Winter wheat, milo, fallow, 3 tons manure on wheat | 0.121 | 0.099 | 18.2 | 440 |
| 555C | Winter wheat, milo, fallow, 3 tons manure on wheat | 0.123 | 0.102* | 18.6 | 458 |
| 556A | Winter wheat, milo, fallow, 6 tons manure on wheat | 0.137 | 0.111 | 19.0 | 520 |
| 560A | Winter wheat, milo, fallow, 12 tons manure on milo | 0.151 | 0.133 | 11.9 | 360 |
| 156A | Winter wheat, fallow, 10 tons manure on fallow, milo, fallow | 0.154 | 0.131 | 14.9 | 460 |
| 156C | Winter wheat, fallow, 10 tons manure on fallow, milo, fallow | 0.140 | 0.135* | 3.9 | 109 |
| 156D | Winter wheat, fallow, 10 tons manure on fallow, milo, fallow | 0.140 | 0.113* | 21.0 | 589 |
| 151A | Winter wheat, rye green manure, milo, fallow | 0.117 | 0.098 | 16.2 | 380 |
| 151D | Winter wheat, rye green manure, milo, fallow | 0.141 | 0.104* | 28.6 | 807 |
| 152A | Winter wheat, rye green manure, milo, corn (wide spaced) | 0.116 | 0.104 | 10.3 | 240 |
| 152D | Winter wheat, rye green manure, milo, corn (wide spaced) | 0.147 | 0.112* | 26.0 | 764 |
| 154A | Winter wheat, field peas green manure, milo, fallow | 0.143 | 0.107 | 25.2 | 720 |
| 154D | Winter wheat, field peas green manure, milo, fallow | 0.136 | 0.113* | 18.4 | 502 |
| 155A | Winter wheat, fallow, milo, fallow | 0.129 | 0.114 | 11.6 | 300 |
| 155D | Winter wheat, fallow, milo, fallow | 0.134 | 0.112* | 17.9 | 480 |
| MCW wheat A | Winter wheat (continuous), late fall plowed | 0.166 | 0.141* | 16.4 | 545 |
| MCW wheat A | Winter wheat (continuous), late fall plowed | 0.166 | 0.142 | 14.5 | 480 |
| MCW wheat B | Winter wheat (continuous), early fall plowed | 0.152 | 0.133* | 13.6 | 415 |
| MCW wheat B | Winter wheat (continuous), early fall plowed | 0.152 | 0.131 | 13.8 | 420 |
| MCS wheat A | Spring wheat (continuous), spring plowed | 0.108 | 0.110 | +1.9 | +40 |
| MCS wheat B | Spring wheat (continuous), early fall plowed | 0.112 | 0.105 | 6.3 | 140 |
| MCW wheat C | Winter wheat, fallow | 0.157 | 0.127 | 20.9 | 655 |
| MCW wheat C | Winter wheat, fallow | 0.157 | 0.120 | 23.6 | 740 |
| MCW wheat D | Winter wheat, fallow | 0.138 | 0.117* | 16.6 | 458 |
| MCW wheat D | Winter wheat, fallow | 0.138 | 0.117 | 15.2 | 420 |
| MCS wheat C | Spring wheat, fallow | 0.118 | 0.107 | 9.3 | 220 |
| MCS wheat D | Spring wheat, fallow | 0.117 | 0.116 | 0.9 | 20 |
| MFW wheat L | Winter wheat, fallow, early spring plowed | 0.168 | 0.132 | 21.4 | 720 |
| MFW wheat M | Winter wheat, fallow, early spring plowed | 0.167 | 0.141 | 15.6 | 520 |
| MC barley B | Barley (continuous), fall plowed | 0.136 | 0.113 | 16.9 | 460 |
| MC barley C | Barley, fallow | 0.123 | 0.111 | 9.8 | 240 |
| MC barley D | Barley, fallow | 0.112 | 0.106 | 5.4 | 120 |
| MC kafir B | Kafir (continuous), late fall plowed | 0.111 | 0.095 | 14.4 | 320 |
| MC kafir C | Kafir, fallow | 0.108 | 0.086 | 20.4 | 440 |
| MC kafir D | Kafir, fallow | 0.106 | 0.086 | 18.9 | 400 |

*1927 analyses.

TABLE 3.—*Changes in the nitrogen content of soil subjected to different treatments during a period of 12 years at Garden City, Kansas.*

| Plat No. | Treatment | Nitrogen in soil 1916 | Nitrogen in soil 1927 1928 | Nitrogen lost in 12 years | |
|---|---|---|---|---|---|
| | | % | % | % | *pounds* |
| 213B | Kafir, milo, Sudan grass | 0.109 | 0.093* | 16.1 | 349 |
| 324A | Winter wheat, winter wheat, kafir, fallow | 0.101 | 0.096* | 5.4 | 109 |
| 324D | Winter wheat, winter wheat, kafir, fallow | 0.099 | 0.088 | 11.1 | 220 |
| 405B | Winter wheat, kafir, fallow | 0.099 | 0.095 | 4.0 | 80 |
| 405C | Winter wheat, kafir, fallow | 0.090 | 0.093* | +3.6 | +65 |
| 331D | Winter wheat, winter wheat, rye green manure, kafir, fallow | 0.090 | 0.085* | 6.1 | 109 |
| *331D | Winter wheat, winter wheat, rye green manure, kafir fallow | 0.090 | 0.084 | 6.6 | 120 |
| 332D | Winter wheat, rye green manure, winter wheat, kafir, fallow | 0.093 | 0.096* | +3.5 | +65 |
| 332D | Winter wheat, rye green manure, winter wheat, kafir, fallow | 0.093 | 0.900 | 3.2 | 60 |
| 83A | Kafir, cowpeas cut for hay, Sudan grass | 0.088 | 0.095 | 8.0 | +140 |
| MCW wheat A | Winter wheat (continuous), late fall plowed | 0.113 | 0.112* | 1.0 | 22 |
| MCW wheat B | Winter wheat (continuous), early fall plowed | 0.107 | 0.104* | 3.1 | 65 |
| MCW wheat B | Winter wheat (continuous), early fall plowed | 0.107 | 0.105 | 1.9 | 40 |
| MCW wheat F | Winter wheat (continuous), early listed | 0.103 | 0.095 | 7.8 | 160 |
| MCW wheat C | Winter wheat, fallow | 0.092 | 0.105 | +15.4 | +284 |
| MCW wheat C | Winter wheat, fallow | 0.092 | 0.095 | +3.3 | +60 |
| MCW wheat D | Winter wheat, fallow | 0.088 | 0.095* | +8.7 | +153 |
| MCW wheat D | Winter wheat, fallow | 0.088 | 0.095 | 8.0 | +140 |
| MFW wheat L | Winter wheat, fallow, early spring plowed | 0.094 | 0.093 | 1.1 | 20 |
| MFW wheat N | Winter wheat, fallow, early spring plowed | 0.099 | 0.092 | 7.1 | 140 |
| MFW wheat O | Winter wheat, fallow, late spring plowed | 0.101 | 0.098* | 3.2 | 65 |
| MFW wheat P | Winter wheat, fallow, late spring plowed | 0.084 | 0.077* | 9.1 | 153 |
| MC barley B | Barley (continuous), early fall plowed | 0.087 | 0.097 | +11.5 | +200 |
| MC kafir A | Kafir (continuous), spring plowed | 0.085 | 0.076* | 11.6 | 196 |
| MC kafir B | Kafir (continuous), fall plowed | 0.084 | 0.074* | 13.0 | 218 |
| MC kafir B | Kafir (continuous), fall plowed | 0.084 | 0.071 | 15.5 | 260 |
| MC kafir C | Kafir (continuous), fall listed | 0.091 | 0.073 | 19.8 | 360 |

*1927 analyses.

Table 4.—*Effect of the original nitrogen content of soils at Hays, Colby, and Garden City upon changes in nitrogen content during a period of 12 years.**

| Nitrogen content, 1916 % | Hays | | Colby | | Garden City | | Total | |
|---|---|---|---|---|---|---|---|---|
| | Number of plats | Average nitrogen loss, pounds | Number of plats | Average nitrogen loss, pounds | Number of plats | Average nitrogen loss, pounds | Number of plats | Average nitrogen loss, pounds |
| 0.08 to 0.10 | — | — | — | — | 15 | 53 | 15 | 53 |
| 0.10 to 0.12 | 1 | 40 | 11 | 233 | 6 | 126 | 18 | 187 |
| 0.12 to 0.14 | 5 | 246 | 10 | 428 | — | — | 15 | 367 |
| 0.14 to 0.16 | 17 | 412 | 9 | 547 | — | — | 26 | 459 |
| 0.16 to 0.18 | 21 | 507 | 3 | 584 | — | — | 24 | 516 |
| 0.18 to 0.20 | 1 | 676 | — | — | — | — | 1 | 676 |

*Correlation coefficient 0.65±.04.

Table 5.—*Effect of small grain crops upon nitrogen changes in the soil during a period of 12 years.*

| Plat No. | Location | Loss or gain in nitrogen, pounds per acre | | | | | |
|---|---|---|---|---|---|---|---|
| | | For each plat | Average of similarly treated plats at various stations | | Average of similarly treated plats at all stations | General average | Grand average |
| | | | Continuous Wheat | | | | |
| MCW* wheat A | Garden City | 22 | | | | | |
| MCW wheat B | Garden City | 53 | | | | | |
| MCW wheat F | Garden City | 160 | | 78 | | | |
| MCW wheat A | Hays | 180 | | | | | |
| MCW wheat B | Hays | 131 | | | | | |
| MCW wheat E | Hays | 340 | | | | | |
| MCW wheat F | Hays | 318 | | | | | |
| 591A | Hays | 393 | | 272 | | | |
| MCS* wheat A | Colby | +40 | | | | | |
| MCS wheat B | Colby | 140 | 50 | | | | |
| MCW wheat A | Colby | 513 | | | | | |
| MCW wheat B | Colby | 418 | 467 | 258 | 219 | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | Wheat-Fallow | | | | |
| MCW | wheat C | Garden City | +172 | | | | | |
| MCW | wheat D | Garden City | +147 | | | | | |
| MFW | wheat L | Garden City | 20 | | | | | |
| MFW | wheat M | Garden City | 140 | | | | | |
| MFW | wheat O | Garden City | 65 | | | | | |
| MFW | wheat P | Garden City | 153 | | 10 | | | |
| MCW | wheat C | Hays | 29 | | | | | |
| MCW | wheat D | Hays | 153 | | | | | |
| MFW | wheat M | Hays | 380 | | 187 | | | |
| MCS | wheat C | Colby | 220 | | | | | |
| MCS | wheat D | Colby | 20 | 120 | | | | |
| MCW | wheat C | Colby | 698 | | | | | |
| MCW | wheat D | Colby | 439 | | | | | |
| MFW | wheat L | Colby | 720 | | | | | |
| MFW | wheat M | Colby | 520 | 594 | 436 | 216 | 217 | |
| | | | | Continuous Barley | | | | |
| MC | barley B | Garden City | +200 | | | | | |
| MC | barley B | Hays | 20 | | | | | |
| MC | barley B | Colby | 460 | | | 93 | | |
| | | | | Barley-Fallow | | | | |
| MC | barley C | Hays | 40 | | | | | |
| MC | barley D | Hays | 140 | | 90 | | | |
| MC | barley C | Colby | 240 | | | | | |
| MC | barley D | Colby | 120 | | 180 | 135 | 117 | 197 |
| | | | | Wheat-Fallow† | | | | |
| 570A | | Hays | 660 | | | | | |
| 570B | | Hays | 895 | | | | | |
| 570C | | Hays | 524 | | | | | |
| 570D | | Hays | 698 | | | | | 694 |

*W = Winter; S = Spring.

†Fallow three years, wheat one year.

Average change, Garden City, 10 plats . . . . . . + 9

Average change, Hays, 11 plats, exclusive of three-year fallow . . . . . . —193

Average change, Colby, 13 plats . . . . . . —344

Average change, Colby, 7 plats, exclusive of winter wheat . . . . . . —166

Average change, Colby, 6 winter wheat plats . . . . . . —551

content of the soil, and subsequent losses evident in Table 4 was established. An examination of the data relative to the nitrogen content of the soil of the two series reveals the fact that there was a maximum difference of over 53% in the nitrogen content of the highest high-nitrogen-containing M. C. winter wheat plats and the lowest low-nitrogen-containing M. C. spring wheat plats, with an average of 34+% in favor of the former for the entire series. With these facts in mind and the data in Table 4 available, it is not difficult to understand why this series and the other duplicate plats to which attention has been called exhibited such marked differences in the nitrogen balance for the 12-year period.

In order that the number of plats falling within a given group in Table 4 might be sufficient to make the results significant, the plats were divided into groups upon a basis of a difference of 0.02% nitrogen. This gave six groups of 15 to 26 plats each, except that only one plat contained more than 0.18% nitrogen. A study of the data presented in Table 4 leaves no doubt that as the nitrogen content of the soils under study increases the losses likewise increase, a fact that should be kept in mind as comparative losses under different treatments are discussed, for there seems to be little doubt but that this factor almost completely overshadows other factors in certain instances.

With these preliminary explanations in mind, attention will be called to some of the tendencies in nitrogen changes indicated by the data.

In the first place, all of the 45 plats analyzed at Hays show losses in nitrogen varying from 29 to 938 pounds per 2,000,000 pounds of soil. The average change in nitrogen recorded for all plats analyzed at Hays was a loss of 435 pounds during the 12-year period.

At Garden City, the data indicate a loss from 15 of the 21 plats analyzed, varying from 20 to 360 pounds, while the remaining 6 registered gains varying from 3 to 272 pounds, with a general average loss of only 69 pounds. In other words, changes in the nitrogen content of the plats examined at Garden City have been relatively slight compared with similar changes at Hays.

At Colby, the data indicate that 1 out of 33 plats examined contained a negligibly higher percentage of nitrogen in 1928 than in 1916. The other 32 registered losses varying from 20 to 764 pounds, the average change for the 33 plats being a loss of 409 pounds per acre.

For convenience in treating the data and also because of the lack of sufficient replication, those plats receiving more or less similar

treatments have been grouped together and the average change in nitrogen content recorded. A few of these are interesting when compared.

Perhaps of first importance would be the influence of single cropping systems, including both continuous and alternating a crop with one or more years fallow. Such systems have been followed at all three points.

At Hays, five continuously cropped wheat plats are consistent in showing relatively small losses, the average being only 272 pounds with a maximum of 393 pounds, or only slightly greater than the admitted experimental error. The corresponding average losses from three Garden City and four Colby continuous wheat plats were 78 and 258 pounds, respectively, with maxima of 160 and 513 pounds per acre. The very wide difference in losses from the winter and spring wheat plats at Colby has already been commented upon. The general average of all 12 continuously cropped wheat plats was 219 pounds, or omitting the two high M. C. winter wheat plats at Colby, 172 pounds, with variations from a slight indicated gain to a loss of 513 pounds per acre.

The average losses from alternate wheat and fallow were for three plats at Hays, 187 pounds; for six plats at Garden City, no loss; and for six plats at Colby, 436 pounds per acre. Again, the losses from the four M. C. winter wheat plats at Colby were very high, ranging from 439 to 720 pounds, with an average of 594 pounds per acre. The M. C. spring wheat series again show very insignificant losses, the average for the two being only 120 pounds per acre. The general average for all 15 alternate wheat and fallow plats was only 209 pounds per acre, or for practical purposes, identical with the continuous wheat plats.

Fallow for three years followed by one year of wheat is evidently conducive of very heavy losses in nitrogen, since the four plats at Hays gave losses varying from 524 to 895 pounds per acre with an average of 694 pounds, compared with an average of 272 pounds and 187 pounds, respectively, for continuous wheat and alternate wheat and fallow.

The single continuous barley plat at Hays showed no loss, at Garden City a possible gain, with a decided loss at Colby, the average for all three being a loss of only 93 pounds. Duplicate alternate barley and fallow plats showed only slight or no losses at both Hays and Colby. The general average of all seven barley plats indicated a loss of only 117 pounds per acre.

With the exception of the winter wheat plats at Colby and possibly the continuous barley plat at the same station, it might be concluded that the small grains, either continuous or alternate crop and fallow, have resulted in very slight or no losses in nitrogen, the average for 27 such plats being only 104 pounds per acre, the maximum 393 pounds, and only 4 of the 27 exceeding 250 pounds. The average for the six winter wheat plats at Colby, however, was 551 pounds. The average loss from all 34 small grain continuously cropped or alternately cropped and fallowed plats was only 193 pounds per acre, or 16 pounds per acre per year.

Sorghums were apparently more conducive to decreases in the nitrogen content of soil than were small grains (Table 6). Continuous kafir induced average losses of 265 pounds (three plats), 320 pounds (one plat), and 422 pounds (two plats) per acre, respectively, at Garden City, Colby, and Hays. The corresponding average losses from alternate kafir and fallow were at Colby, 420 pounds (duplicate), and at Hays, 640 pounds (duplicate) per acre. The average loss from the six continuous kafir plats was 326 pounds and from the four alternate kafir and fallow plats 530 pounds per acre.

The losses from milo plats were even heavier than from kafir, an average of duplicates at Hays being, for continuous milo 597 pounds and alternate milo and fallow 807 pounds per acre. Since milo was compared only at Hays, it would be unfair to compare it with kafir grown at the other two points, hence the following comparative figures for Hays: Average loss from four kafir plats 531 pounds and for four milo plats 702 pounds per acre.

The general average loss from all 14 sorghum plats, 8 continuously cropped and 6 alternate cropped and fallowed, was 492 pounds per acre compared with 193 pounds for the small grain crops.

The average losses under rotations consisting essentially of one or two small grain crops, a sorghum or corn, and one year of fallow were 139 pounds (five plats), 407 pounds (three plats), and 541 pounds (five plats) per acre, respectively, at Garden City, Colby, and Hays, with a general average of 355 pounds per acre, a value intermediate between the losses under small grain and sorghum cropping systems.

The losses under somewhat comparable rotations that included a green manure crop of rye or peas (Table 7) were on the average not perceptibly different. No losses were evident in the three Garden City green manure plats. At Hays eight such plats gave an average loss of 273 pounds, while the corresponding average loss from six green manured plats at Colby was 569 pounds, the value for Hays

TABLE 6.—*Effect of sorghums upon the changes in the nitrogen content of soil during a period of 12 years.*

| Plat No. | Location | Loss or gain in nitrogen, pounds per acre: For each plat | Average of similarly treated plats at various stations | Average of similarly treated plats at all stations | General average | Grand average |
|---|---|---|---|---|---|---|
| | | | Continuous Kafir | | | |
| MC kafir A | Garden City | 196 | | | | |
| MC kafir B | Garden City | 239 | | | | |
| MC kafir C | Garden City | 360 | 265 | | | |
| MC kafir B | Hays | 284 | | | | |
| MC kafir E | Hays | 560 | 422 | | | |
| MC kafir B | Colby | 320 | 320 | 326 | | |
| | | | Kafir-Fallow | | | |
| MC kafir C | Hays | 757 | | | | |
| MC kafir D | Hays | 524 | 640 | | | |
| MC kafir C | Colby | 440 | | | | |
| MC kafir D | Colby | 400 | 420 | 530 | 408 | |
| | | | Continuous Milo | | | |
| MC milo B | Hays | 393 | | | | |
| MC milo E | Hays | 800 | 597 | | | |
| | | | Milo-Fallow | | | |
| MC milo C | Hays | 937 | | | | |
| MC milo D | Hays | 676 | 807 | | 702 | 492 |

being appreciably lower, while that for Colby was appreciably higher than for the corresponding rotations without green manure crop. No differences were evident in the losses from eight plats in which peas were the green manuring crop and nine plats where rye served the same purpose.

TABLE 7.—*Effect of rotations with and without a green manure crop upon the changes in the nitrogen content of soil during a period of 12 years.*

| Plat No. | Location | Loss or gain in nitrogen, pounds per acre: For each plat | Average of similarly treated plats at the various stations | Average of similarly treated plats at all stations | General average |
|---|---|---|---|---|---|
| | | Rotation Alone | | | |
| 213B | Garden City | 349 | | | |
| 324A | Garden City | 109 | | | |
| 324D | Garden City | 220 | | | |
| 405B | Garden City | 80 | | | |
| 405C | Garden City | +65 | 139 | | |
| 552B | Hays | 938 | | | |
| 553A | Hays | 560 | | | |
| 57A | Hays | 380 | | | |
| 57C | Hays | 458 | | | |
| 57D | Hays | 371 | 541 | | |
| 552A | Colby | 440 | | | |
| 155A | Colby | 300 | | | |
| 155D | Colby | 480 | 407 | 355 | |
| | | Rotation With Green Manure* | | | |
| 83A | Garden City | +140 | +140 | | |
| 54A | Hays | 200 | | | |
| 54D | Hays | 196 | | | |
| 56A | Hays | 320 | | | |
| 56B | Hays | 349 | | | |
| 56D | Hays | 305 | 274 | | |
| 154A | Colby | 720 | | | |
| 154D | Colby | 502 | 611 | 306 | |
| | | Rotation With Green Manure† | | | |
| 331D | Garden City | 115 | | | |
| 332D | Garden City | +3 | 56 | | |
| 53A | Hays | 160 | | | |
| 53D | Hays | 218 | | | |
| 55A | Hays | 440 | 273 | | |
| 151A | Colby | 380 | | | |
| 151D | Colby | 807 | | | |
| 152A | Colby | 240 | | | |
| 152D | Colby | 764 | 548 | 347 | 340 |

*Green manure crop of Canada field peas.
†Green manure crop of rye.

TABLE 8.—*Effect of rotations plus stable manure or straw upon changes in the nitrogen content of soil during a period of 12 years.*

| Plat No. | Loss or gain in nitrogen, pounds per acre: For each plat | Average of similarly treated plats at both stations | General average |
|---|---|---|---|
| | | Hays | |
| 554A | 640 | | |
| 555A | 360 | | |
| 555B | 829 | | |
| 556A | 600 | | |
| 556B | 764 | | |
| 559A | 180 | | |
| 559B | 676 | | |
| 560A | 140 | | |
| 560B | 676 | 541 | |
| | | Colby | |
| 554A | 320 | | |
| 555A | 440 | | |
| 555C | 458 | | |
| 556A | 520 | | |
| 560A | 360 | | |
| 156A | 460 | | |
| 156C | 109 | | |
| 156D | 589 | 407 | 478 |

Heavy losses (Table 8) were in evidence from practically all 17 rotated plats receiving stable manure or, in two instances only, straw, the average of 541 pounds for nine plats at Hays being somewhat larger than the 407-pound average for eight plats at Colby. The general average of 478 pounds for the 17 plats receiving such treatment was practically as large as for any other type of treatment, in spite of the fact that 11 of these plats received barnyard manure at the rate of 6 to 12 tons per acre every three or four years. Unfortunately, no determinations were made of the nitrogen content of the manure, but assuming it to be of average composition, and owing to the low rainfall above the average in nitrogen, it probably contained at least 12 pounds per ton.

## DISCUSSION

Before directing attention to differences in the nitrogen balance that apparently have arisen from different methods of treatment or other factors, perhaps the point should be emphasized that the data in most comparisons drawn are not regarded as being conclusive. In fact, we hesitate in presenting data containing, as these do, numerous instances where supposed replications do not check any better, and to which at the same time, it is impossible to apply statistical treatment of the data. However, a great deal of interest has been manifest during the past few years in the nitrogen problem in dry-land agriculture and this fact, coupled with the extreme dearth of

direct data bearing upon this important problem, would seem to justify the presentation of any new information that may be available. Furthermore, it is believed that the data herein presented are both quantitatively and qualitatively superior to any that have previously been presented along similar lines. In addition, it will probably be another 10 or 15 years before further analyses of the plats under study will be warranted. It is hoped that the tendencies indicated in these data are of sufficient importance to stimulate the interest of others so situated as to accumulate data along similar lines. If this can be accomplished, it is felt that the publication of these data is justified aside from any other value which they may possess.

Worthy of major consideration perhaps is the very large and rapid losses of nitrogen that these data indicate may take place in cultivated dry-land soils. Unfortunately the first analyses do not represent the original nitrogen content of the virgin soil in any instance, all the plats studied having been under cultivation for some time prior to the first analysis. Analyses of the most representative sod soil available at the time the first samples were taken indicate that probably considerable nitrogen originally present in the virgin soil had already been lost. For example, such a sod collected at Colby contained 0.182% nitrogen, a value exceeding the nitrogen of other plats recorded in Table 2 by from 8 to 72%. There is no question but that if such losses as are indicated continue, it is only a matter of a few years before nitrogen and not moisture must become the limiting factor in crop production in western Kansas. How low the nitrogen must fall before the soil will no longer supply an adequate quantity for the maximum utilization of available moisture, or how long it may take, remain to be determined.

There are pretty strong indications in these data that the nitrogen may not fall far below the lower levels now present in certain plats before it reaches a fairly constant level at which the agencies contributing nitrogen to the soil counterbalance those responsible for its removal. In fact, there are some indications that with the lower nitrogen levels, gains in the nitrogen content may be expected. For example, an examination of the data in Table 9 indicates that under small grain cropping systems those plats which, in 1916, contained less than 0.1% nitrogen have on the average, actually gained in nitrogen or at least have shown no losses. Also, the 10 continuously cropped or alternate cropped and fallowed small grain plats at Garden City show an average loss of only 10 pounds of nitrogen per acre for the 12 years.

TABLE 9.—*Effect of original nitrogen content of soil upon changes in the nitrogen content during a period of 12 years, small grain cropping systems.**

| Range in nitrogen content of soil | Hays: Number of plats | Hays: Nitrogen losses in pounds per acre, Range | Hays: Average | Colby: Number of plats | Colby: Nitrogen losses in pounds per acre, Range | Colby: Average | Garden City: Number of plats | Garden City: Nitrogen losses in pounds per acre, Range | Garden City: Average | Total: Number of plats | Total: Nitrogen losses in pounds per acre, Range | Total: Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| % | | | | | | | | | | | | |
| 0.08 to 0.10 | | | | | | | 6 | +200 to —153 | +34 | 6 | +200 to —153 | +34 |
| 0.10 to 0.12 | 1 | | 40 | 5 | + 40 to —220 | — 92 | 4 | — 22 to —160 | —75 | 10 | + 40 to —220 | — 80 |
| 0.12 to 0.14 | 3 | — 20 to —140 | — 63 | 3 | —240 to —460 | —380 | | | | 6 | — 20 to —460 | —221 |
| 0.14 to 0.16 | 4 | —131 to —380 | —251 | 2 | —418 to —698 | —558 | | | | 6 | —131 to —698 | —353 |
| 0.16 to 0.18 | 7 | —180 to —895 | —524 | 3 | —513 to —720 | —584 | | | | 10 | —180 to —895 | —542 |

*Correlation coefficient 0.747±.048.

Of the 38 small grain plats, 6 with original nitrogen content of less than 0.1% show an average gain of 34 pounds; 10 with original nitrogen content between 0.1% and 0.12% show an average loss of only 80 pounds with a maximum loss of 220 pounds for the 12 years. In other words, no plat in this series showed a significant change in nitrogen content if the original nitrogen content was less than 0.12%.

Attention may again be called to Table 4 in which the relationship between original nitrogen content and changes taking place in the entire 99 plats are recorded. The average loss for 15 plats containing originally less than 0.1% nitrogen has been only 53 pounds regardless of treatment, or the 33 containing less than 0.12% nitrogen originally gave an average loss of only 126 pounds per acre for the 12-year period.

That the data as to correlation between original nitrogen content and subsequent changes are significant is quite evident from the correlation coefficient which for the 38 small grain plats was found to be 0.747 ±0.048 and for the entire 99 plats 0.64 ±0.04.

It would appear from these data that around 0.1% nitrogen represents the level to which the nitrogen content of soils of this region may be expected to fall and remain fairly constant in spite of nitrogen removed in crops, drainage, etc. If this be true, then two very important and fundamental questions arise, namely. (a) At this level, or at any particular level to which they may fall, Will the soil supply an adequate quantity of nitrogen to produce the maximum yields with the moisture that is available? (b) What are the natural agencies that take care of the losses, and are there any farming practices that might be brought into play that would facilitate their activity?

At the present time there is very little information available bearing directly upon either of these questions. The application of stable manure at the three points has not resulted very beneficially upon crop production or upon checking nitrogen losses where information is available, i.e., at Hays and Colby. However, an examination of the data in Tables 1 and 2 will show that at Hays the applications of manure have been made to the highest nitrogen containing plats, i. e., plats with a nitrogen content in 1916 varying from 0.160% to 0.188%, while at Colby the original nitrogen content of plats receiving manure varied from 0.121% to 0.154%. In other words, manure has in no case been applied to plats that these data would indicate as being in need of nitrogen, or that possibly possess the ability of retaining any added nitrogen. Likewise, the growth of a legume as a green manure crop has had little, if any, effect upon

crop production or nitrogen balance. The growth of such crops, though, are as a rule very limited and nothing is known as to the value of legumes as a means of adding nitrogen to a soil under conditions of such limited available moisture.

As previously mentioned, Sievers and Holtz (6) have reported remarkable responses from the application of nitrate nitrogen to wheat under eastern Washington conditions, comparable, at least in so far as rainfall is concerned, to the conditions in western Kansas. There is urgent need for more information along these lines and it would seem that experiments similar to those of Sievers and Holtz would be justified at other points where the rainfall is limited and the nitrogen content of the soil is especially low. Such experiments should determine whether nitrogen ever becomes the limiting factor in crop production under semi-arid conditions.

As to the agencies that may be responsible for the addition of nitrogen to the surface soil, Stewart has suggested the translocation of nitrogen from lower levels to the surface soil and the fixation of nitrogen by the free-living nitrogen-fixing organisms. Of these two suggestions, the latter seems to the writers to be the most probable. The examination of large numbers of cultivated and virgin soils of western Kansas reveals the presence of a very active Azotobacter flora in the cultivated and a complete absence of these organisms from sod soils. How long after a soil is brought under cultivation before an Azotobacter flora becomes established and active is not known. If it be assumed that such organisms are primarily responsible for any increases in nitrogen, then losses might be expected to continue until such time as an active flora may become well established. Furthermore, it has been repeatedly claimed, backed by some well-founded data, that these organisms do not exercise their maximum nitrogen-fixing capacity in soils well supplied with nitrogen. The relationship of the nitrogen content of the soil to the fixation of nitrogen by Azotobacter has been discussed by Greaves and Nelson (2) and needs no further comment save that they noted increases in nitrogen content of field soils with a nitrogen content of approximately 0.1%, but that when the nitrogen content was materially raised by the addition of stable manure losses instead of gains were registered.

In addition to the probable effect that the nitrogen content of the soil has had upon subsequent changes and the possible low losses occurring under small grain culture, other effects of the cropping system are indicated. Sorghums, either continuous or alternating with fallow, are apparently conducive of much more marked de-

creases in the nitrogen content of the soil than are the small grains. Similarly, rotations, consisting essentially of a small grain and a sorghum or corn with a year of fallow, have caused marked decreases in the nitrogen content, especially at Hays and Colby. A green manure included in the rotation was apparently without effect at Colby, but on the average, lowered the losses at Garden City and Hays.

When stable manure was applied at some point in a rotation at Hays and Colby, it apparently had no beneficial effect in maintaining a higher nitrogen content than a rotation without manure, the general average losses under the two systems being identical at both points. Because of the relatively low losses under a rotation without manure at Garden City, the general average loss of all manured plats was somewhat higher than for the corresponding rotation without manure.

The heaviest losses under any system of treatment took place in the three-year fallow, one year wheat plats. This may have been due to the translocation of nitrogen to lower levels, such movement being facilitated by the higher moisture content due to prolonged fallowing. Also, the limited quantity of organic residue returned to the soil only once in four years may have furnished an insufficient supply of energy material for the nitrogen-fixing organisms. Or, finally, the marked accumulation and prolonged existence of nitrates, that would undoubtedly obtain in the absence of any utilization of nitrates by higher plants, might lead to the setting free of nitrogen by some little understood biological phenomenon. Such losses with unsatisfactory explanations have frequently been reported.

## SUMMARY

The nitrogen content of 99 plats, located at three different points in semi-arid western Kansas, was determined in 1916 and again in 1927 and 1928. The quantities of nitrogen found at both analyses, together with the treatments to which the plats have been subjected, are reported in this paper.

These data would seem to indicate the following relative to the nitrogen changes taking place in these soils during this short period of time:

1. Very large losses of nitrogen may take place under certain conditions.

2. The principal factor governing the nitrogen balance for this period seems to have been the nitrogen content of the soil at the beginning of the period. A correlation coefficient of $0.64 \pm 0.04$ was found between the original nitrogen content and changes taking place in the nitrogen content for the entire 99 plats, or for 38 similarly cropped plats the corresponding value was $0.747 \pm 0.048$.

3. Of the various cropping systems compared, continuous small grain or alternate small grain and fallow seemed to be conducive of the smallest changes in nitrogen content. One year of grain and three years of fallow apparently induced very large losses.

Sorghums (kafir and milo), either continuous or alternating with fallow, also caused relatively large losses.

The data relative to the influence of the various rotations are less conclusive, being complicated by the influence of the nitrogen content of the soil at the beginning, but on the average the losses were much greater than for small grain alone and less than for the sorghums. Losses when stable manure was added in a rotation were very high in spite of the nitrogen added in the manure, but again the influence of the original nitrogen content was probably partially responsible for such heavy losses.

4. There are indications that when the nitrogen content of the soil in this region falls to approximately 0.1% the factors responsible for additions of nitrogen to the soil will counterbalance those tending to cause its removal, thereby establishing a nitrogen equilibrium near this level. The very important question is raised whether at such a low nitrogen level the soil will be able to supply an adequate quantity of soluble nitrogen to enable the maximum utilization of the available moisture.

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# THE INFLUENCE OF "MOTES" ON THE YIELD AND BOLL-SIZE OF THE COTTON PLANT[1]

H. E. REA[2]

The occurrence of "motes," or aborted ovules, in many of the upland varieties of cotton is rather common.[3] These motes fail to produce any lint or seed of commercial value and it would appear that an abundance of motes would tend to lower the yield of the cotton plant. In order to determine the relationship between yield of seed cotton and the size of boll per plant to the percentage of motes produced per plant, a series of correlation studies were made involving these characteristics.

A random sample of each of 16 varieties of cotton grown in the regular variety test at Substation No. 5, Temple, Texas, was secured in 1925 to be used in this study. The yield of seed cotton, the average weight of seed cotton per boll, and the percentage of motes characteristic of each of 50 individual plants within the several varieties were determined. The yield is reported in grams of seed cotton produced per plant and the size of boll in the average number of grams of seed cotton produced per boll. The percentage of motes is given as a ratio of the total number of motes to the total number of ovules. Similar data were obtained for 1926.

The correlation coefficients between yield and percentage of motes are presented in Table 1. A study of this table will reveal that of 32 coefficients listed only 3 show significant relationships. The varieties Sunshine, Truitt, and Anton have coefficients that were significant in 1925. In this connection attention is called to the fact that a very large number of factors necessarily affect the yield of the cotton plant and it would be rather preposterous to expect many single factors to show significantly high correlations with yield. Numerous attempts to analyze the yield of the cotton plant have failed to bring out a very close relationship between yield and many of the other individual characteristics of the plant. Although few of the coefficients in Table 1 are statistically significant, it is rather striking that 26 of the 32 coefficients show negative relationship. This preponderance of negative coefficients indicates distinctly the tendency of motes to reduce yield.

[1]Contribution No. 472 from the Department of Agronomy, Texas Agr. Exp. Station, College Station, Texas.

[2]Agronomist.

[3]REA, H. E., Location of "motes" on the upland cotton lock. Jour. Amer. Soc. Agron., 20: 1064–1068. 1928. Varietal and seasonal variation of motes in upland cotton. Jour. Amer. Soc. Agron., 21: 481–486. 1929.

TABLE 1.—*Coefficients of correlation between yield of seed cotton and percentage of motes per plant for cotton varieties of 1925 and 1926 at Temple, Texas.*

| Variety | 1925 | 1926 |
|---|---|---|
| Sunshine | —0.47±.08 | +0.14±.10 |
| Anton | —0.41±.09 | —0.15±.11 |
| Truitt | —0.38±.08 | +0.12±.12 |
| Harper | —0.31±.09 | +0.04±.11 |
| New Boykin | —0.30±.09 | —0.30±.10 |
| Cliett's Superior | —0.30+.09 | —0.19±.14 |
| Belton | —0.29±.09 | —0.06±.11 |
| Rowden | —0.22±.09 | —0.01±.11 |
| Lankart | —0.21±.10 | —0.01±.11 |
| Kasch | —0.18±.09 | —0.30±.10 |
| Mebane | —0.18+.09 | —0.14±.13 |
| Qualla | —0.12±.14 | +0.07+.12 |
| Snowflake | —0.08±.09 | —0.20±.10 |
| Lonestar | —0.07±.10 | +0.20±.10 |
| Acala | +0.04±.09 | —0.14+.11 |
| Durango | —0.02±.10 | —0.35±.10 |

TABLE 2.—*Coefficients of correlation between average size of boll and percentage of motes per plant for cotton varieties of 1925 and 1926 at Temple, Texas.*

| Variety | 1925 | 1926 |
|---|---|---|
| Sunshine | —0.83±.03 | —0.02±.11 |
| Lankart | —0.70±.05 | —0.64±.07 |
| Truitt | —0.68±.05 | —0.46±.09 |
| Kasch | —0.59±.07 | —0.07±.11 |
| Harper | —0.58±.06 | —0.64±.07 |
| Qualla | —0.55±.10 | —0.72±.06 |
| New Boykin | —0.55±.07 | —0.35±.10 |
| Cliett's Superior | —.053±.07 | —0.38±.12 |
| Durango | —0.52±.07 | —0.56±.07 |
| Mebane | —0.50±.07 | —0.59±.09 |
| Lonestar | —0.50±.07 | —0.03±.11 |
| Belton | —0.49±.07 | —0.48±.08 |
| Anton | —0.47±.09 | —0.09±.12 |
| Rowden | —0.36±.08 | —0.41±.09 |
| Snowflake | —0.43+.08 | —0.71±.05 |
| Acala | —0.16±.09 | —0.36±.10 |

There is a striking and significant relationship between the percentage of motes and the size of bolls as is brought out in Table 2. Out of 32 correlations between these two characteristics, all show negative relationship and 24 are statistically significant. Nine varieties show significant correlations for both years. These varieties are Lankart, Qualla, Harper, Durango, Snowflake, Truitt, Mebane, Belton, and Rowden. The varieties which showed high coefficients for percentage of motes and the size of boll were Sunshine, Lankart, and Truitt in 1925; and Qualla, Snowflake, Lankart, and Harper in 1926.

The results of these correlation studies justify the conclusion that, although the relationship is not very close, the association between the percentage of motes and the yield of seed cotton per plant is negative in most cases.

The percentage of motes per plant is closely associated with the average size of boll per plant and the relationship is negative, that is, the higher the percentage of motes, the smaller the boll.

# THE EFFECT OF CERTAIN INJURIES TO LEAVES OF CORN PLANTS UPON WEIGHTS OF GRAIN PRODUCED[1]

A. N. Hume and Clifford Franzke[2]

Leaves of corn may suffer injury not only from various causes but also at various stages in the growth of the plants. The present investigations, without attempting to classify sources of injury, do attempt to describe three kinds of leaf injury that are frequent, and to measure their effects in terms of grain produced. Likewise, these effects are measured as occurring at several stages of growth separately, for the reason that definite injuries to growing plants of corn evidently depend very much for their ultimate outcome upon whether the plant is young or advanced toward maturity at the time the leaves are injured.

## THREE TYPES OF LEAF INJURY

One of the commonest injuries that comes to the leaf blades of Indian corn consists in the tearing or splitting of the laminae, resulting often in their becoming severed longitudinally from the midrib for about half the length from tip to ligule. This type of injury was considered as being perhaps the one most frequently observed regardless of its effect upon plant functions.

The second type of leaf injury selected for study consisted in the same longitudinal splitting of the leaf blades with the additional flexing and breaking of the midrib at a point midway between the tip and ligule of the leaf. These two types of leaf injury were assumed somewhat arbitrarily to be "minor" injuries which might have a depressing though not very decisive effect upon the growth of vegetative parts or on the amount of grain harvested. The results obtained proved this assumption to be correct.

A third type of leaf injury consisted in the entire removal of all free leaf blades which might be developed at successive stages of growth of the corn plant. The leaves were usually severed from the plant by tearing off at or slightly below the ligule. It was assumed that this type of injury would be classified as "severe."

[1]Contribution from the Department of Agronomy, South Dakota Agr. Exp. Station, Brookings, S. Dak. Presented at the annual meeting of the Society held in Washington, D. C., November 23, 1928. Received for publication May 13, 1929.

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## ARRANGEMENT OF INJURED AND UNINJURED CORN ROWS FOR INVESTIGATION IN 1926

In the spring of 1926 a portion of a field of corn was laid off for this investigation consisting of a total of 34 rows not including borders. Each of these rows was 36 hills long with the hills 44 inches apart. After the corn was planted and young plants safely up, the stand was thinned to one plant per hill. A number of these plants later died while others put out tillers, accounting for some irregularity in final stand.

In the case of rows where the first type of injury was to be inflicted, a knife blade was drawn longitudinally through the leaf blades on each side of the midrib in such a way that the laminae were severed therefrom for about half the length. Other rows where the second type of leaf injury was inflicted had the laminae severed from the midribs longitudinally for half their length with a knife blade as just described, after which the separated midribs were held with two hands and flexed to breaking at a point about the middle of their length. In the case of rows where corn plants had leaves removed, the operation was performed simply by taking the leaf blade in the right hand at a point sufficiently close to the stalk and pulling it sharply downward until the entire leaf blade broke away. All the leaf blades present on certain of the corn rows at given dates were thus removed, leaving the plants usually with only such portions of their leaves as would be contained in the sheaths.

Four of the 34 rows in the series were left with all plants entirely uninjured to serve as check rows. Two of these check rows were situated on the west side of the series and two on the east side. The rows extended north and south. Thus the several groups of rows with leaves injured were situated between the two pairs of check rows. The total number of injured rows was 30, arranged in 10 groups of 3 each.

Thus 1 row in each of the 10 groups was subjected to leaf injuries of one of the types already explained, on each of ten successive dates, at which time the corn plants had come to specified stages of maturity.

All the rows of corn were given the usual amount of cultivation along with the remainder of the field of corn in which this experiment was located. In addition, after cultivation was discontinued, all weeds were removed once by hand hoeing at the close of the growing season.

## HARVESTING AND STORING

When the several rows of corn were evidently ripe, all of the stalks were cut and tied into bundles, the harvest from each row thus being put into a bundle by itself. The bundles were then stored in a barn where they remained until thoroughly air dry. After the bundles were thus thoroughly air dried, the corn was separated from the fodder and the weights of corn per row determined separately.

## 1926 RESULTS

Table 1 serves at once as an outline of the relative position of the 34 rows, numbering consecutively from west to east, and also as giving the date when each type of leaf injury was inflicted upon one row of each group of three rows, the weight of air-dry shelled corn actually harvested, and the computed yields of corn in bushels per acre from the several rows.

In Table 1 the dates of leaf injuries of the several types are of importance largely because they indicate the stage of growth of the corn plants at the time the injury occurred. These successive dates and stages of growth at the corresponding dates were as follows: July 10, knee high, two joint stage; July 22, tasseling, 10–12 leaf stage; July 27, ear buds just shooting, nearly all stalks tasseled; August 2, plants varied from beginning of pollination to kernel formation, most of the kernels at pre-milk stage; August 7, plants varied in degree of maturity, average at early blister stage; August 14, late blister stage; August 23, milk stage; August 28, late milk stage or early dough stage; September 4, some ears beginning to dent; September 11, corn dented.

## 1927 RESULTS

Similar experiments were continued in the 1927 season. The results of the two seasons were consistent with one another, consequently, before completing a discussion of the 1926 season, the 1927 results will be reported.

The arrangement of the rows where leaves of the plants were uninjured and injured for comparison was slightly different in 1927 than in 1926, due in part to interspersing check rows more frequently and to the introduction into the test of additional factors of injury. The rows in this experiment were 4 rods long with hills 44 inches apart.

The hills were planted with two or more kernels per hill and were later thinned to one stalk per hill. Every ninth row was a check row and the rows upon which types of leaf injury were inflicted were interspersed regularly between these checks.

TABLE 1.—*Yields in pounds per row (1926) of air-dry shelled grain from corn plants with and without given leaf injuries.*

| Row No. | Type of injury | Date of injury | Grain produced Pounds per row | Bushels per acre |
|---|---|---|---|---|
| 1 | Check, leaves uninjured | — | 12.7 | 20.3 |
| 2 | Check, leaves uninjured | — | 11.3 | 18.1 |
| 3 | Leaves split | | 13.9 | 22.2 |
| 4 | Split+midribs broken | July 10 | 15.2 | 24.4 |
| 5 | Leaves stripped | | 7.4 | 11.8 |
| 6 | Leaves split | | 12.6 | 20.2 |
| 7 | Split+midribs broken | July 22 | 13.4 | 21.5 |
| 8 | Leaves stripped | | 0.7 | 1.1 |
| 9 | Leaves split | | — | 21.5* |
| 10 | Split+midribs broken | July 27 | 12.5 | 20.0 |
| 11 | Leaves stripped | | — | 2.0* |
| 12 | Leaves split | | — | 21.5* |
| 13 | Split+midribs broken | Aug. 2 | 13.7 | 22.0 |
| 14 | Leaves stripped | | 1.9 | 3.0 |
| 15 | Leaves split | | 14.2 | 22.8 |
| 16 | Split+midribs broken | Aug. 7 | 13.5 | 21.6 |
| 17 | Leaves stripped | | 4.1 | 6.6 |
| 18 | Leaves split | | 12.9 | 20.6 |
| 19 | Split+midribs broken | Aug. 14 | 15.1 | 24.2 |
| 20 | Leaves stripped | | 5.3 | 8.5 |
| 21 | Leaves split | | — | 22.3* |
| 22 | Split+midribs broken | Aug. 23 | 13.7 | 22.0 |
| 23 | Leaves stripped | | — | 11.8* |
| 24 | Leaves split | | 15.0 | 24.0 |
| 25 | Split+midribs broken | Aug. 28 | 14.5 | 23.2 |
| 26 | Leaves stripped | | 9.4 | 15.0 |
| 27 | Leaves split | | 15.3 | 24.5 |
| 28 | Split+midribs broken | Sept. 4 | 13.8 | 22.1 |
| 29 | Leaves stripped | | 11.6 | 18.6 |
| 30 | Leaves split | | 13.0 | 20.8 |
| 31 | Split+midribs broken | Sept. 11 | 13.1 | 20.9 |
| 32 | Leaves stripped | | 12.7 | 20.4 |
| 33 | Check, leaves uninjured | | — | — |
| 34 | Check, leaves uninjured | | 16.2 | 25.9 |

*Average of similar preceding and succeeding yields.

Table 2 indicates the relative position of the rows, beginning on the north and numbering toward the south, the direction of the rows themselves extending east and west; as well as the type of leaf injury inflicted, the pounds of ear corn harvested, the weight of shelled corn, and the computed bushels of shelled corn per acre.

TABLE 2.—*Yields in pounds per row (1927) of air-dry ear corn and of shelled corn from plants with or without given types of leaf injury, computed to bushels per acre.*

| Row No. | Type of injury | Date of injury | Ear corn, pounds per row | Shelled corn, pounds per row | Shelled corn, bushels per acre |
|---|---|---|---|---|---|
| 1 | Check | | 6.4 | 4.8 | 15.3 |
| 3 | Leaves split | | 8.8 | 6.2 | 19.9 |
| 4 | Split+midribs broken | July 7 | 7.8 | 6.0 | 19.1 |
| 5 | Leaves stripped | | 6.5 | 4.8 | 15.3 |
| 7 | Leaves split | | 8.0 | 5.8 | 18.7 |
| 8 | Split+midribs broken | July 14 | 7.5 | 5.7 | 18.2 |
| 9 | Leaves stripped | | 3.4 | 2.5 | 8.0 |
| 10 | Check | | 7.9 | 5.7 | 18.2 |
| 12 | Leaves split | | 7.8 | 5.5 | 17.7 |
| 13 | Split+midribs broken | July 21 | 5.9 | 4.5 | 14.5 |
| 14 | Leaves stripped | | 2.1 | 1.1 | 3.4 |
| 16 | Leaves split | | 6.5 | 4.5 | 14.5 |
| 17 | Split+midribs broken | July 28 | 7.0 | 5.4 | 17.3 |
| 18 | Leaves stripped | | 0.8 | 0.4 | 1.4 |
| 19 | Check | | 9.5 | 7.2 | 23.0 |
| 21 | Leaves split | | 7.0 | 5.2 | 16.6 |
| 22 | Split+midribs broken | Aug. 4 | 6.1 | 4.5 | 14.5 |
| 23 | Leaves stripped | | 0.4 | 0.2 | 0.6 |
| 25 | Leaves split | | 8.0 | 5.8 | 18.7 |
| 26 | Split+midribs broken | Aug. 11 | 7.5 | 5.2 | 16.6 |
| 27 | Leaves stripped | | 2.7 | 2.1 | 6.8 |
| 28 | Check | | 8.2 | 6.2 | 19.8 |
| 30 | Leaves split | | 8.0 | 5.7 | 18.2 |
| 31 | Split+midribs broken | Aug. 18 | 4.2 | 3,2 | 10.2 |
| 32 | Leaves stripped | | 4.2 | 3.1 | 10.0 |
| 34 | Leaves split | | 7.6 | 5.7 | 18.2 |
| 35 | Split+midribs broken | Aug. 25 | 6.6 | 5.0 | 16.0 |
| 36 | Leaves stripped | | 4.2 | 3.1 | 10.0 |
| 37 | Check | | 8.0 | 5.7 | 18.2 |
| 39 | Leaves split | | 6.6 | 4.7 | 15.0 |
| 40 | Split+midribs broken | Sept. 1 | 7.9 | 6.0 | 19.3 |
| 41 | Leaves stripped | | 7.6 | 5.4 | 17.3 |
| 43 | Leaves split | | 9.2 | 7.0 | 22.5 |
| 44 | Split+midribs broken | Sept. 8 | 10.2 | 7.2 | 23.0 |
| 45 | Leaves stripped | | 8.3 | 6.6 | 21.1 |
| 46 | Check | | 9.7 | 7.1 | 22.7 |

Examination of the yields reported in Table 2 indicates that in 1927, as in 1926, stripping the leaves caused a reduction in the amount of shelled corn. Likewise, it will be noted that the greatest

reduction in yield occurred when the injury was inflicted at an intermediate stage in the growth of the corn plant, neither at the beginning nor at the close of the growing period. The same relationship was true in 1926.

It was also observed that the lighter injuries to leaves caused by splitting the blades or by splitting the blades plus breaking the midribs produced a smaller reduction in yield of grain. A comparison of yields from plants so injured at an early stage of growth (July 7) with the nearest check indicates that the yield of the latter in this instance was even below that of the plants with the slight leaf injuries, indicating perhaps that these specific leaf injuries caused reductions in yield of shelled corn, if any, that were within the coefficient of error in these experiments. However, in all other instances where these slighter leaf injuries occurred at later stages of growth, the degree of injury indicated by comparison with the nearest check was appreciable. It is hardly possible to discover by a comparison of the yields in adjoining rows whether any additional reduction in yield takes place due solely to the breaking of midribs of the leaves of corn plants.

## AVERAGE YIELDS FOR 1926 AND 1927

It is apparent that the results put down in Tables 1 and 2 are generally consistent. Accordingly, amounts of shelled corn produced from the several injured and uninjured rows which are available for both 1926 and 1927 may be combined. This is done by taking the average of yields of shelled corn from corresponding rows in 1926 and 1927. It may be well to note again in this connection that certain actual yields are missing from this series in Table 1. In attempting to compute the two-year averages and locate the corresponding points on the chart in Fig. 1, these missing yields are arbitrarily replaced by utilizing the average of the nearest available similar yields in the series, one preceding and one following.

It will be noted in Fig. 1 that all lines indicating yields from corn plants having leaves injured in any degree between the dates of July 7 and Aug. 25 fall below the line of normal yield. Previous to and following these dates, the lines generally curve upward, approaching or, in some instances, slightly exceeding the line of normal yields. The latter instances occur in the two intermittent lines which indicate slighter degrees of leaf injury.

The yield line for plants having the leaf blades stripped away, although approaching normal at the extremes, always falls decidedly below normal. The lowest point in this line occurs at Aug. 2, 1926, and July 28, 1927, and the line rises regularly on each side of this point.

The lines showing the yields following the lesser degrees of injury cross and recross one another so that it is not easy to determine by observation whether one is actually higher than the other.

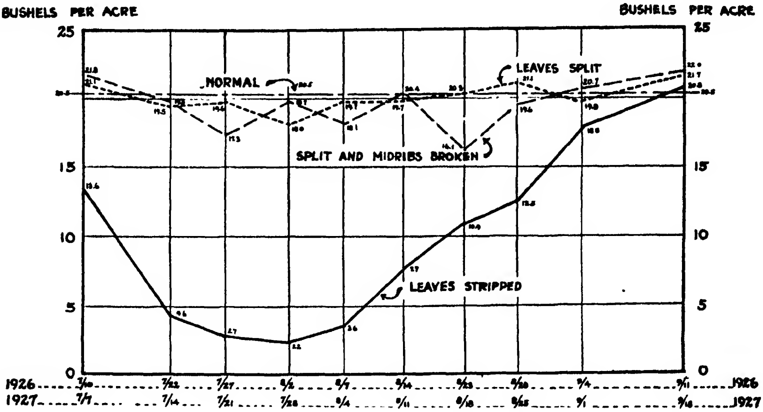


FIG. 1.—Showing the average yields for 1926 and 1927 for corn plants subjected to various leaf injuries as compared with uninjured plants.

## DISCUSSION OF RESULTS

The productien of lesions in the leaves of corn plants to the extent of removing all developed leaf blades (laminae) therefrom at whatever period of growth always resulted in a decided depression of the amount of grain produced. It is evident also that the greatest depression occurs when leaf blades are thus removed at a stage of growth in the plants noted as "tasseling to kernel formation." Plants in this experiment having leaf blades entirely removed at the stages of growth indicated produced 2.2 bushels per acre as compared with a normal yield of 20.5 bushels—a reduction of 89.3%. The reduction in yield was regularly less when these severe lesions occurred at periods previous to or following the stage of growth indicated, so that apparently the period of tasseling to kernel formation may be defined as a most critical time for such severe leaf injuries to occur.

It was also indicated that even the less severe lesions used in this experiment produced relatively their greatest reduction in grain yield when they occurred at this critical period in the life of the plant. Thus, even splitting the leaves of corn plants at this time of growth would evidently interfere somewhat with their function in helping to bring the grain to maturity.

The average yield of grain from all plants with the leaves split was 20.1 bushels per acre and that from the plants with the leaves split and the midribs broken, 19.5 bushels per acre. The very slight difference in these averages hardly serves as an indication that the sole factor of breaking the midribs in itself interfered with the functions of the leaves as indicated by amount of grain produced.

The outstanding observation in this study was the apparent fact that, under the conditions of the experiments, the most sensitive time to leaf injury in the development of the corn plant is at or near the time of tasseling or shooting. When the leaves were actually injured at the time indicated, a corresponding reduction in yield of grain resulted. If corn leaves were injured only slightly at this time, the corresponding reduction in yield was small; but plants suffering the entire removal of the leaves at or about tasseling time were only able to mature nominal amounts of grain.

It is of equal interest to note that when leaf injuries occurred, under the conditions of the tests, at periods either before or following this time of greatest sensitiveness, the damage to the plant and the corresponding reduction in yield of grain was reduced accordingly. In other words, the leaves of the youngest corn plants in this experiment which had all of the developed leaf blades removed suffered a loss of about half of their capacity to produce shelled corn, while similar leaf injuries produced at successively later and later stages in the growth of the plants resulted in gradually more and more reduction in yield until the maximum reduction was reached from injuries inflicted at tasseling time. After this, a succession of similar leaf injuries produced less and less reduction in yield of grain until the stage of practical maturity was reached when leaf injuries had apparently no effect on yield of grain.

The foregoing generalizations may prove interesting in observing the reduction in yield of corn and consequent loss due to hail which may injure the leaves of the corn plant in different degrees and at various stages of development.[3] If analogies may be drawn between the results obtained in these experiments and the effects of hail upon the corn plant, a light hail storm which only shreds the outer ends of the leaves and breaks down an occasional midrib will cause a minimum of damage in the final yield of grain. If, however, the same analogy may be followed, a hail storm heavy enough to tear off leaf blades will cause appreciable damage at any time during the development of the corn plant, being most serious at the tasseling

[3]DUNGAN, G. H. Effect of hail injury on the development of the corn plant. Jour. Amer. Soc. Agron., 20: 51–54. 1928.

stage. Perhaps a hail storm at tasseling time severe enough to tear off all the developed leaf blades might reduce the final yield 89% or more. Pursuing the analogy further, the same hail storm occurring early in the development of the plants, say when the latter were knee-high at the two-joint stage, might reduce the amount of grain produced about 33%. Still further, if the same storm occurs after the corn is dented, the loss in grain may be negligible, as indicated by the experiment where yields from corn injured thus at maturity were practically equal to normal yields.

The writers do not desire to pursue too far the analogy between the present results and losses due to hail. For present purposes it is sufficient to point out the possible application of the principles involved to the computation of crop risk and insurance, the actual applications perhaps being made later after additional data have been accumulated.

The writers feel, too, that although the present results seem fairly consistent, there is still room for further careful observation of all conditions under which injuries to the corn plant may occur. It is not conclusively established, for example, that the lesions caused to corn leaves in this experiment are analogous to the effects of hail, though they appear to be the same. A knife blade drawn carefully through a leaf blade on each side of the midrib is not a hail storm, though it may be the only available substitute.

It remains to measure in a similar manner the effects of other kinds and degrees of injury on leaves and other parts of the corn plant. These injuries may be caused by hail, insects, fungi, or other agencies. Perhaps this paper will suggest that, although these several injuries are numerous, they will be measurable, and once resolved and accurately measured, may be used as a basis for actuarial or other computations.

Obviously, the injuries and their effects are related to the physiology of the corn plant itself. For example, the apparent reason why injuries to the leaves of young plants, even to the extent of removing those developed at an early stage of growth, are less serious than injuries inflicted later in the development of the plant, is that young corn plants have power to develop other leaves and make recovery. Removing all the leaves from older corn plants finds them with less and less power to put out new leaves, and consequently, with less chance to recover. This is especially true up to the critical stage of shooting and tasseling when the development of the leaves is complete. After this stage, leaf functions are less and less important to the plant until maturity, when the leaves have done their work and injury to them alone has no effect in reducing the yield of grain.

# WHEN THE SOIL MULCH CONSERVES MOISTURE[1]

Chas. F. Shaw[2]

The effectiveness of the soil mulch as a means of conserving soil moisture has been under discussion for many years. Early experiments, notably those made by King (3)[3] between 1885 and 1900, showed that the soil mulch was quite effective in reducing the amount of water that was evaporated from the surface of the soil. In one of these experiments reported in 1889, the water table was maintained at a depth of 22 inches below the surface. The soil mulches were produced by removing the required depth of soil, mixing it by hand and replacing it on the undisturbed soil column. The results showed that the mulches reduced the evaporation losses to less than one-half that of the bare soil. On the basis of this and many other similar experiments has rested the conviction that the soil mulch, made by stirring the soil by cultivation, would reduce evaporation losses and aid materially in conserving the soil moisture.

In 1917, Call and Sewell (1) published the results of their studies, showing that at Manhattan, Kansas, mulching the soil not only did not increase the amount of moisture in the soil, but that the mulched plats actually lost more moisture than did the bare, undisturbed plats. Many similar experiments were reported during the ensuing years, the most complete and conclusive being those of Veihmeyer (6) in 1927. Carefully conducted experiments showed that mulching by thorough cultivation at weekly intervals failed to save any soil moisture, the differences in moisture content between the mulched and unmulched plats being insignificant. The water table at these locations was from 18 to 40 or more feet below the surface.

As a result of these later experiments, there appears to be a growing opinion that the mulch can not function as a means of reducing losses of soil moisture by evaporation. The evidence submitted is very conclusive, both for and against the efficiency of the mulches. It should be noted, however, that in each case where the soil mulch was effective the water table was relatively close to the surface, while in those cases where it was ineffective, the ground water level

[1]Contribution from the Division of Soil Technology, University of California, Berkeley, Calif. Received for publication May 20, 1929.

[2]Professor of Soil Technology.

[3]Reference by number is to "Literature Cited," p. 1171.

was many feet below the surface of the soil. With a deep water level the soil moisture in the upper horizons of the soil would be distributed by downward directed capillarity. The moisture content in these horizons would be at or near the normal moisture capacity (4) and movement to the surface in the liquid phase would be impossible. Since the water evaporated from the soil surface must be brought there by capillary rise, losses by evaporation can only take place when the water table is within capillary reach of the surface.

Shaw and Smith (5) have shown that the limit of capillary rise of water through the Yolo sandy loam and Yolo loam was not more than 10 feet, while with the water table at 4 and 6 feet the capillary rise and surface evaporation was quite rapid. They concluded that for sandy loams and loams in general water tables at 10 feet or more below the surface would be below the maximum height of capillary rise and that there would be no movement of water to the surface. Hilgard (2) also showed the maximum capillary rise to be not over 10 feet even when using soil separates having the greatest water lifting power.

## EXPERIMENTAL WORK

In order to redetermine whether or not the soil mulch would reduce evaporation losses when the water table was within easy capillary rise to the surface, certain experiments, similar to those of King, Hilgard, and others, were undertaken. Four tubes of galvanized iron, 8 inches in diameter and 4 feet in length, were filled with Yolo sandy loam. This was tamped in with care to avoid stratification and to give an even volume weight of 1.15. The soil had a moisture equivalent of 16 and in the air-dry condition contained about 3% moisture.

The tubes were placed in closed individual tanks with reservoirs that automatically maintained a constant water level. The tops of the soil tubes were enclosed in a tunnel made of roofing paper on a wooden frame, and a constant flow of air over the soil surfaces was maintained by a 12-inch electric fan located at one end of the tunnel. The tops of the tubes projected about an inch above the floor of the tunnel.

All the soils were irrigated with sufficient water to penetrate through the full depth, capillary rise from the tanks taking place at the same time. The tubes were set up on November 18, 1926, and the adjustment of moisture within the soil was allowed to proceed until March 31, 1927, when the mulching experiment was started.

Tubes II and IV were mulched on this date, and tubes I and III were compacted, some additional soil being added to the two latter tubes in order to have them all full to the top. Tubes II and IV were again cultivated on September 22, October 27, and November 23, 1927, and on January 12, February 8, and March 9, 1928. The cultivation was done with a harrow-like implement consisting of a block of wood with nails or spikes that permitted a thorough stirring of the soil to a depth of 2 inches. During the intervals of four or five weeks between cultivations, the stirred layer would become moist in the lower one-half to two-thirds inch, while during the six-month period (March 31 to September 22) without cultivation the mulch became moist to the surface.

TABLE 1.—*Cumulative loss of water in ml from mulched and unmulched soils, first period, with initial treatment.*

| Date | Days elapsed | Mulched Tube II | Mulched Tube IV | Not mulched Tube I | Not mulched Tube III |
|---|---|---|---|---|---|
| April 5, 1927 | 0 | 0 | 0 | 0 | 0 |
| May 13, 1927 | 38 | 298 | 70 | 500 | 1,825 |
| Aug. 25, 1927 | 142 | 1,710 | 1,650 | 3,160 | 3,805 |
| Sept. 22, 1927 | 170 | 2,100 | 2,020 | 3,750 | 4,310 |
| Sept. 29, 1927 | 177 | 2,415 | 2,370 | 3,970 | 4,560 |
| Oct. 6, 1927 | 184 | 2,415 | 2,370 | 4,110 | 4,940 |
| Oct. 13, 1927 | 191 | 2,415 | 2,370 | 4,110 | 4,940 |
| Oct. 20, 1927 | 198 | 2,415 | 2,370 | 4,450 | 5,160 |
| Oct. 27, 1927 | 205 | 2,530 | 2,530 | 4,450 | 5,380 |
| Nov. 3, 1927 | 212 | 2,530 | 2,690 | 4,375 | 5,700 |
| Nov. 10, 1927 | 219 | 2,710 | —— | 4,910 | 5,910 |
| Nov. 17, 1927 | 226 | 2,870 | 2,940 | 5,100 | 5,910 |
| Nov. 25, 1927 | 234 | 2,870 | 2,940 | 5,220 | 6,130 |
| Dec. 1, 1927 | 240 | 3,160 | 3,200 | 5,365 | 6,570 |
| Dec. 19, 1927 | 258 | 3,340 | 3,200 | 5,720 | 6,900 |
| Jan. 12, 1928 | 272 | 3,570 | 3,650 | 6,360 | 7,300 |
| Jan. 19, 1928 | 289 | 3,870 | 3,950 | 6,360 | 7,365 |
| Feb. 2, 1928 | 303 | 3,970 | 4,110 | 6,850 | 7,770 |
| Feb. 17, 1928 | 318 | 4,190 | 4,250 | 6,860 | 7,790 |
| Feb. 24, 1928 | 325 | 4,190 | —— | 6,860 | 7,790 |
| March 2, 1928 | 331 | 4,190 | 4,320 | 6,890 | 7,900 |
| March 10, 1928 | 339 | 4,530 | 4,620 | —— | 7,950 |
| March 16, 1928 | 345 | 4,530 | 4,620 | 7,190 | 8,000 |
| March 23, 1928 | 352 | 4,530 | 4,620 | 7,280 | —— |
| March 30, 1928 | 359 | 4,835 | 4,950 | 7,390 | 8,225 |
| April 6, 1928 | 366 | 4,835 | 4,950 | 7,490 | 8,225 |
| April 12, 1928 | 372 | 4,835 | 4,950 | 7,550 | 8.300 |
| Rate per day | 372 | 13.00 | 13.30 | 20.29 | 22,31 |
| Treatment average | | 13.15 | | 21.30 | |

The cumulative loss of water during this period of 372 days is shown in Table 1 and in Fig. 1A. The apparent irregularity in rate of loss is due to the manner of delivery of water from the automatic reservoirs. When the water level in the tanks was lowered about one-fourth inch, air could enter the reservoir and water would flow

into the tank until the original level was reached. The quantity delivered at one time was considerable, usually sufficient to supply the losses for two or three weeks. Apparent irregularities in the rate of loss occurred when readings were made just before or just

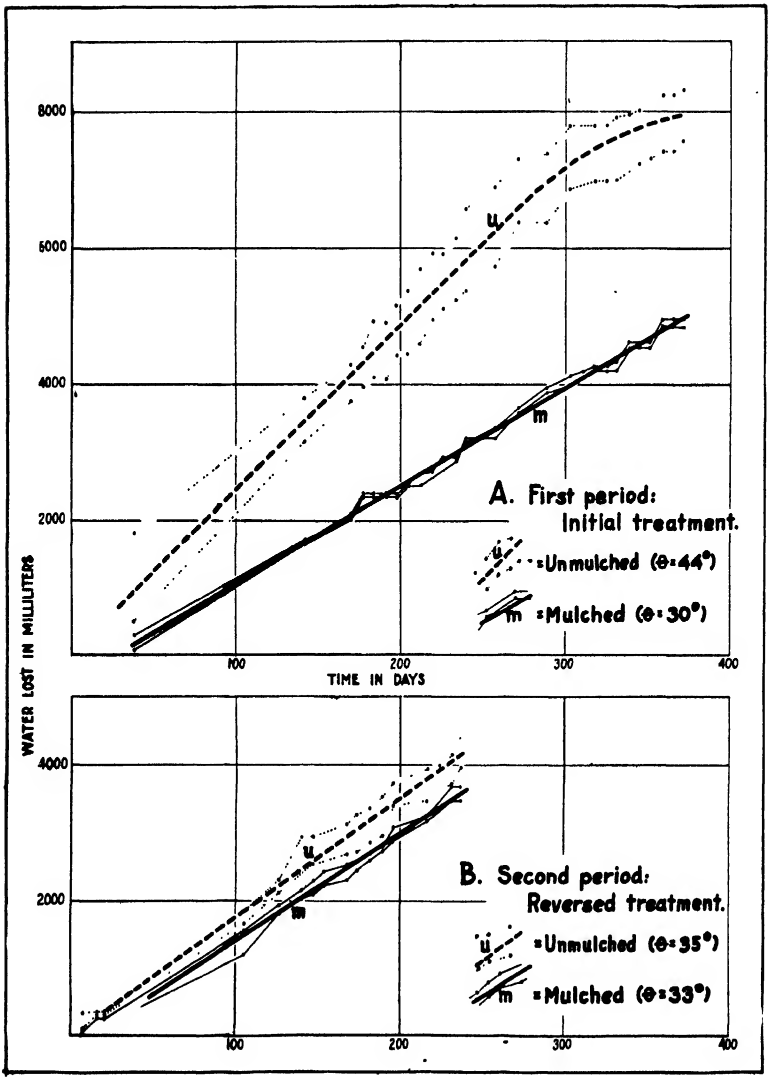


FIG. 1.—Curves showing cumulative loss of moisture from mulched and unmulched tubes through (A) the first period, with initial treatment, and (B) the second period, with treatments reversed.

after the flow of water from the reservoir. (The tanks were covered and all possible care was taken to prevent evaporation or leakage.) The mulched tubes lost 4,835 ml and 4,950 ml, respectively, while the unmulched tubes lost 7,550 ml and 8,300 ml during this period of 372 days. The average daily loss from the two mulched tubes was 13.15 ml and from the two unmulched tubes 21.30 ml. The rate of loss was strikingly constant, as shown by the lines U and M in Fig. 1A. M is a straight line from the start of the record at 38 days to the end, the angle of slope being approximately 30°. U is straight for 280 days, with an angle of slope of about 44°, but during the last 92 days the rate of loss slowly decreased. No explanation is offered to account for this change in rate of loss. The decrease in total evaporation, or saving of soil moisture due to the mulch, is 38% as compared to the loss from the unmulched tubes.

In order to check these results it was determined to reverse the experiment, compacting the soil on tubes II and IV which had previously been mulched, and mulching tubes I and III which had been compacted. Excess soil due to loosening the surface of the latter tubes was transferred to those that were compacted, in order to maintain the soil surfaces even with the top of the metal tubes. It was later found that the added soil did not make a firm contact and adhere to the soil of the column, but that it cracked loose and formed a surface plate or layer that undoubtedly reduced the moisture movement to the soil surface and the evaporation therefrom.

Tubes I and III were mulched again on August 11 (after four months), August 23, August 30, September 27, and October 26, 1928. On December 4, 1928, the experiment was discontinued. When the covers were removed from the tanks the water level was found to be at the proper height and a study of the soil columns showed no unusual condition other than the surface plate on tubes I and III previously mentioned. The cumulative loss of moisture during this second period of 236 days is given in Table 2 and Fig. 1B.

Again the rate of loss from each pair of tubes was found to be fairly constant, but the differences between the mulched and unmulched tubes were not significant. The average loss from the mulched tubes was 15.15 ml per day, while that from the unmulched tubes was 17.80 ml. The low rate of loss from the unmulched tubes is ascribed to the cracking loose of the layer of added soil. The difference in loss shows a saving of 13.77% due to the mulching. The slopes of the lines M and U on the graph (Fig. 1B) are approximately 33° and 35°.

TABLE 2.—*Cumulative loss of water from mulched and unmulched soils, second period, with treatments reversed.*

| Date | Days elapsed | Mulched Tube I | Mulched Tube III | Not mulched Tube II | Not mulched Tube IV |
|---|---|---|---|---|---|
| April 12, 1928 | 0 | 0 | 0 | 0 | 0 |
| April 19, 1928 | 7 | 90 | 0 | 55 | 350 |
| April 28, 1928 | 16 | 320 | 0 | 265 | 350 |
| May 3, 1928 | 21 | 320 | 0 | 265 | 350 |
| July 26, 1928 | 105 | 1,540 | 1,200 | 1,675 | 1,840 |
| Aug. 16, 1928 | 126 | 1,930 | 1,800 | 2,125 | 2,310 |
| Aug. 30, 1928 | 140 | 2,110 | 2,000 | 2,125 | 2,930 |
| Sept. 3, 1928 | 144 | — | — | 2,515 | — |
| Sept. 6, 1928 | 147 | 2,300 | 2,090 | 2,515 | 2,940 |
| Sept. 13, 1928 | 154 | 2,420 | 2,220 | — | — |
| Sept. 27, 1928 | 168 | 2,525 | 2,310 | 2,685 | 3,120 |
| Oct. 3, 1928 | 174 | — | 2,440 | 2,685 | 3,280 |
| Oct. 11, 1928 | 182 | 2,660 | 2,600 | 2,865 | 3,360 |
| Oct. 18, 1928 | 189 | 2,790 | 2,730 | 2,950 | 3,530 |
| Oct. 25, 1928 | 196 | 3,085 | 2,870 | 3,405 | 3,730 |
| Nov. 15, 1928 | 217 | 3,210 | 3,180 | 3,465 | 3,940 |
| Nov. 22, 1928 | 224 | 3,490 | — | — | — |
| Nov. 30, 1928 | 231 | 3,670 | 3,485 | 3,685 | 4,160 |
| Dec. 4, 1928 | 236 | 3,670 | 3,485 | 3,945 | 4,460 |
| Rate per day | 236 | 15.55 | 14.76 | 16.71 | 18.89 |
| Treatment average | | 15.15 | | 17.80 | |

These experiments, conducted under controlled conditions, give results that agree with those of King and the other earlier investigators. With water tables within easy capillary reach of the surface, the mulch reduced the rate of evaporation of moisture from the soil. However, when the water table is so deep that capillary rise can not lift the water to the surface, there can be no losses of soil moisture that the mulch can materially reduce. If the conclusions of Hilgard, Shaw and Smith, and others are correct, capillary rise can not lift water through soils for distances much over 10 feet, then in those places where the water table is deeper than 10 feet below the surface, the soil mulch can not show any material effect on the soil moisture.

In this discussion the loss of moisture in the vapor phase has not been mentioned. The air in moist soils occupies the otherwise empty pore spaces and is enclosed by more or less continuous water films. It probably is always at a condition of saturation or maximum relative humidity. This vapor would be lost by slow diffusion through the soil to the atmosphere, and also by the outflow of moist air and the inflow of drier air occasioned by changes in barometric pressure. As the soil mulch is looser and more porous than an uncultivated surface, it would not decrease these movements of soil air. The mulch might reduce the warming and cooling of the soil and so reduce the volume of air flowing in or out of the soil because of thermal changes. It is not believed that the soil mulch will materially affect the vapor movements of soil moisture.

A careful study of all the evidence shows that the soil mulch is effective in reducing evaporation when the water table is high and within capillary reach of the surface. It would also function when a hardpan, claypan, or other more or less impervious substratum prevented the downward movement of water and produced a "perched" water table above the true ground water level.

*The soil mulch can reduce the loss of soil moisture only when the water table, perched or permanent, is within capillary rise of the surface.* But under such conditions, it may not be necessary to make any effort to conserve water. Growing plants would find an abundance of moisture within their rooting zone. Under arid conditions, alkali accumulations in injurious amounts would ultimately occur, though effective mulches might reduce the rate of such accumulation. With high water tables, the soil moisture problem would be that of drainage to get rid of excess water rather than that of mulching to conserve water.

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# REGISTRATION OF IMPROVED WHEAT VARIETIES, IV[1]

J. ALLEN CLARK, J. H. PARKER, AND L. R. WALDRON[2]

In continuing the registration of new varieties on the basis of performance, this paper is the report of the 1928–29 Sub-committee of the Society on wheat. Four earlier reports presented the registration of 261 varieties. The first (2)[3] was the registration of 229 standard varieties. In 1926, 23 improved varieties (3) were registered. In 1927, five (4), and in 1928 four (5) improved varieties also were registered. Certificates of registration have been issued for the improved varieties. Another paper (1) contains an alphabetical list of the first 252 registered varieties, their registration number, class, origin, and estimated acreage in 1924.

Applications for the registration of additional varieties have been received by the committee. Those which have been approved this year are here registered.

| Varietal Name | Registration No. |
|---|---|
| Purkof | 263 |
| Tenmarq | 264 |
| Kawvale | 265 |

The origin and performance, which constitute the basis for registration of these varieties, are as follows.

## PURKOF, REG. No. 263

Purkof (Purdue No. 10C–5–2–4, C. I. No. 8381) was produced from a hybrid between Michigan Amber and Malakof made in 1912, and last selected in 1915, at the Purdue University Agricultural Experiment Station. The variety has been under experiment by the agronomy department for 12 years and has been distributed by them for commercial growing. It is reported as, "a soft red winter wheat with a semi-hard tendency. It usually shows some hard kernels and is often classified mixed on the market." Its superior characters are high yields under Indiana conditions, outstanding

[1]Registered under cooperative agreement between the Bureau of Plant Industry, U. S. Department of Agriculture, and the American Society of Agronomy. Received for publication, November 20, 1929.

[2]Senior Agronomist in Charge of Western Wheat Investigations, Office of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture; Professor of Crop Improvement, Kansas Agricultural College, Manhattan, Kans.; and Plant Breeder, North Dakota Agricultural Experiment Station, Fargo, N. Dak., respectively; members of 1928–29 Sub-committee of the American Society of Agronomy for the Registration of Wheat Varieties.

[3]Reference by number is to "Literature Cited." p. 1174.

winterhardiness, stiff straw, non-shattering, and ability to stand up for a long time after the crop is dead ripe. The comparative yield data of Purkof and Fultz winter wheats are shown in Table 1.

TABLE 1.—*Comparative yield data of Purkof and Fultz winter wheats in plats at Indiana Experiment Stations, 1922–28.*

| Variety | Yield in bushels per acre | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1922 | 1923 | 1924 | 1925 | 1926 | 1927 | 1928 | Average |
| LaFayette | | | | | | | | |
| Purkof........ | — | 38.8 | 26.9 | 37.5 | 42.9 | 37.6 | 19.0 | 33.7 |
| Fultz......... | — | 33.9 | 24.8 | 31.0 | 33.6 | 36.3 | 5.1 | 27.4 |
| Bedford | | | | | | | | |
| Purkof........ | 22.8 | 25.0 | 11.7 | 28.3 | 34.4 | 18.0 | 15.2 | 22.2 |
| Fultz......... | 20.7 | 28.4 | 6.6 | 20.6 | 30.6 | 8.4 | 1.7 | 16.7 |
| North Vernon | | | | | | | | |
| Purkof........ | 19.6 | 43.6 | 20.5 | 27.5 | 25.2 | 18.0 | 22.6 | 25.3 |
| Fultz......... | 24.9 | 34.1 | 23.6 | 25.7 | 19.2 | 12.8 | 7.2 | 21.1 |
| Farmland | | | | | | | | |
| Purkof........ | — | 5.6 | 14.4 | 20.7 | 34.5 | 31.8 | 15.5 | 20.4 |
| Fultz......... | — | 10.9 | 16.5 | 16.9 | 25.2 | 30.3 | 0.0 | 16.6 |
| Vincennes | | | | | | | | |
| Purkof........ | — | — | — | 27.0 | 38.6 | 27.5 | 29.4 | 30.7 |
| Fultz......... | — | — | — | 23.5 | 36.2 | 23.4 | 1.7 | 21.2 |

## TENMARQ, REG. No. 264

Tenmarq (Kans. No. 439, C. I. No. 6936) was produced from a hybrid between Marquis and P-1066. The latter is a selection similar to Kanred, both from Crimean, C. I. No. 1435. The cross was made in 1917 from the crop of 1916–17 at Manhattan, Kans., and Tenmarq is the result of a selection made in 1921. It was developed by the agronomy department of the Kansas Agricultural Experiment Station in cooperative experiments with the Office of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture.

Tenmarq is bearded and has white glabrous glumes, long beaks, and short hard red kernels. It is a true winter wheat, but the grain is sometimes graded as hard red spring or mixed. Its superior characters are high yield, excellent quality, early maturity, and stiff straw. Its chief defects are that it is susceptible to Hessian fly attack and has only slightly greater winterhardiness than Blackhull. Tenmarq was selected, and has been tested in nursery experiments since 1922, by John H. Parker (6) who applied for its registration. The yields from plat experiments, supplied by S. C. Salmon, are given in Table 2. In 1928, Tenmarq was included in seven county cooperative tests with farmers. In 1929, it was included in 47 county cooperative tests with farmers.

TABLE 2.—*Comparative yield data of Tenmarq and four standard varieties of hard red winter wheat grown in plat experiments at Agronomy Farm, Manhattan, Kans., 1925–29.*

| Variety | Kansas No. | C. I. No. | Yield in bushels per acre 1925 | 1926 | 1927 | 1928 | 1929 | Av. | Yield in % of Kanred |
|---|---|---|---|---|---|---|---|---|---|
| Tenmarq (new) | 439 | 6936 | 41.4 | 37.9 | 47.5 | 50.5 | 24.3 | 40.3 | 117.2 |
| Blackhull (standard) | 343 | 6251 | 37.4 | 34.1 | 41.1 | 46.8 | 18.1 | 35.5 | 103.2 |
| Kanred (standard) | 2401 | 5146 | 39.0 | 36.3 | 35.5 | 46.4 | 14.8 | 34.4 | 100.0 |
| Kharkof (standard) | 382 | 2193 | 33.7 | 30.6 | 35.3 | 45.5 | 14.2 | 31.9 | 92.7 |
| Turkey (standard) | 570 | 1558 | 34.5 | 34.7 | 32.4 | 44.7 | 12.8 | 31.8 | 92.4 |

## KAWVALE, REG. No. 265

Kawvale (Kans. No. 2593, C. I. No. 8180) was developed at Manhattan, Kans., from a selection made in 1918 from Indiana Swamp, a synonym of the Valley variety. The experiments were cooperative between the agronomy department of the Kansas Agricultural Experiment Station and the Office of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture.

Kawvale is bearded, with white glabrous glumes and soft to semi-hard red kernels. It is of the soft red winter class and its superior characters are high yield, a high degree of resistance to leaf rust, and some resistance to Hessian fly attack. It was developed in the breeding nursery by John H. Parker (6) who applied for its registration. The yield results from plat experiments, supplied by S. C. Salmon, are shown in Table 3. Kawvale was included in a few county cooperative tests with farmers in 1928 and in many more in 1929.

TABLE 3.—*Comparative yield data of Kawvale and three standard varieties of soft red winter wheat grown in plat experiments at Agronomy Farm, Manhattan, Kans., 1926–29.*

| Variety | Kansas No. | C. I. No. | Yield in bushels per acre 1926 | 1927 | 1928 | 1929 | Av. | Yield in % of Fulcaster |
|---|---|---|---|---|---|---|---|---|
| Kawvale (new) | 2593 | 8180 | 39.2 | 43.8 | 46.8 | 29.5 | 39.8 | 102.6 |
| Fulcaster (standard) | 317 | 6471 | 42.6 | 44.0 | 41.6 | 26.9 | 38.8 | 100.0 |
| Harvest Queen (standard) | 19 | 6199 | 34.3 | 33.7 | 40.4 | 19.6 | 32.0 | 82.5 |
| Currell (standard) | 501 | 3326 | 32.0 | 30.7 | 36.8 | 19.9 | 29.9 | 77.1 |

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# REGISTRATION OF VARIETIES AND STRAINS OF OATS, IV[1]

T. R. STANTON, E. F. GAINES, AND H. H. LOVE[2]

During the past year the following improved varieties of oats have been approved for registration on the basis of merit and performance. These varieties, together with those registered in previous years (3, 4, and 5)[3] make a total of 35 improved varieties which have been registered.

| Group and Varietal Name | Registration No. |
|---|---|
| *Spring oats* | |
| Early red: | |
| Brunker | 73 |
| Midseason yellow: | |
| Rainbow | 74 |
| Midseason white: | |
| Anthony | 75 |
| Miami | 76 |
| Wayne | 77 |

The descriptions and records of these varieties, on which approval for registration is based, are summarized here for the information of those interested in better oat varieties.

## BRUNKER, REG. No. 73

Brunker (C. I. No. 2054) was originated as a pure line from Burt at the Akron Field Station, Akron, Colo., of the U. S. Department of Agriculture, in 1919. The original plant row was isolated by F. A. Coffman, under whose direction the variety also was subsequently developed. Brunker was grown in head row number 16, in 1919, and thereafter it was known as Burt No. 916. The collection of panicles used for sowing this series of head rows was made by T. R. Stanton

[1]Registered under cooperative agreement between the Bureau of Plant Industry, U. S. Department of Agriculture, and the American Society of Agronomy. Received for publication November 21, 1929.

[2]Senior Agronomist in charge of Oat Investigations, Office of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture; Associate Professor of Farm Crops, and Cerealist, Washington State College and Agricultural Experiment Station, and Agent, Office of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture; and Professor of Plant Breeding, New York State College of Agriculture and the Agricultural Experiment Station at Cornell University, and Collaborator, Office of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture, respectively. Members of the 1929 Subcommittee of the American Society of Agronomy for the Registration of Oat Varieties.

[3]Reference by number is to "Literature Cited," p. 1180.

from fields of Burt in the southeastern states during a field trip in the spring of 1918. Brunker was first distributed to farmers in 1929. The application for registration was submitted by F. A. Coffman. The general description of the variety which accompanied the application is as follows:

Brunker is a very early variety of the red oat (*Avena byzantina*) group, maturing even earlier than Fulghum. The straw is rather short and slender, with a typical reddish tinge. The panicles are small and equilateral, with short, spreading branches. Spikelets usually are 2-flowered, sometimes 3-flowered. Lemmas reddish, with an occasional slender awn on the lower floret of the spikelet; basal hairs usually present, nerves somewhat prominent. Under favorable conditions the variety produces plump kernels of good bushel weight. It has shown considerable resistance to some physiologic strains of *Ustilago avenae* which infect other red oats, such as Fulghum.

Brunker has been tested in replicated field plats at Akron for seven years, and at North Platte, Nebr., for five years. The annual and average acre yields of Brunker, Kherson (standard), Colburt, and Fulghum at these stations, are shown in Tables 1 and 2. Both Colburt and Fulghum are grown on farms in northeastern Colorado, and it seems desirable to include data on them for comparison.

TABLE 1.—*Annual and average acre yields of the Brunker, Kherson, Colburt, and Fulghum oat varieties for the years indicated at the Akron Field Station, Akron, Colo.*

| | Acre yield in bushels | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Variety | 1921* | 1922* | 1923 | 1924 | 1927 | 1928 | 1929 | Average |
| Brunker (new) | 21.9 | 39.8 | 45.0 | 13.1 | 51.6 | 56.7 | 14.4 | 34.6 |
| Kherson (standard) | 23.3 | 28.1 | 34.8 | 6.6 | 46.8 | 44.7 | 13.0 | 28.2 |
| Colburt | 31.5 | 35.1 | 42.4 | 7.2 | 46.7 | 40.3 | 12.7 | 30.8 |
| Fulghum | 17.5 | 33.6 | 40.9 | 7.6 | 50.1 | 52.8 | 23.0 | 32.2 |

*Yields from comparable one-hundredth-acre plats. Yields for remaining years are from quadruplicated fortieth-acre plats.

TABLE 2.—*Annual and average acre yields of the Brunker, Kherson, Colburt, and Fulghum oat varieties for the years indicated at the North Platte Substation, North Platte, Nebr.*

| | Acre yield in bushels | | | | | |
|---|---|---|---|---|---|---|
| Variety | 1924 | 1925 | 1926 | 1927 | 1928 | Average |
| Brunker (new) | 31.2 | 30.9 | 1.9 | 57.8 | 65.5 | 37.5 |
| Kherson (standard) | 29.4 | 21.6 | 2.8 | 57.6 | 62.5 | 34.8 |
| Colburt | 31.6 | 18.7 | 2.2 | 56.9 | 58.4 | 33.6 |
| Fulghum | 35.5 | 30.6 | 3.5 | 51.6 | 50.4 | 34.3 |

The area to which Brunker is adapted appears to be limited to northeastern Colorado, southwestern Nebraska, and northwestern Kansas.

## RAINBOW, REG. No. 74

Rainbow (No. Dak. No. 22006, and C. I. No. 2345) was originated at the North Dakota Agricultural Experiment Station, Fargo,

N. Dak., as a pure line from the Green Russian variety. The plant selection was made by T. E. Stoa in 1922. Application for registration was made by the department of agronomy of the North Dakota station. It was first distributed to farmers of North Dakota in the spring of 1929. Rainbow is a midseason yellow oat with equilateral panicles, resembling very closely the Green Russian parent. Its desirable characters are high resistance to stem rust, high-yielding ability, and a fairly stiff straw. Rainbow has been tested in fortieth-acre plats at Fargo since 1925. The annual and average acre yields of Rainbow as compared with Victory and Gopher, standard midseason and early varieties, respectively, and the Green Russian parent are shown in Table 3.

TABLE 3.—*Annual and average acre yields of Rainbow, Victory, Gopher and Green Russian varieties grown in triplicated fortieth-acre plats at Fargo, N. Dak., in the years indicated.*

| | Acre yield in bushels | | | | | |
|---|---|---|---|---|---|---|
| Variety | 1925 | 1926 | 1927 | 1928 | 1929 | Average |
| Rainbow (new) | 97.0 | 88.6 | 95.8 | 75.6 | 76.7 | 86.7 |
| Victory (standard midseason) | 96.2 | 76.7 | 47.8 | 81.1 | 66.9 | 73.7 |
| Gopher (standard early) | 113.0 | 72.0 | 72.0 | 80.1 | 78.0 | 83.0 |
| Green Russian (parent) | 109.3 | 80.6 | 67.3 | 76.6 | 68.1 | 80.4 |

## ANTHONY, REG. No. 75

Anthony (Minnesota No. 686, and C. I. No. 2143) was originated as a selection from a White Tartar (White Russian) x Victory cross at University Farm, St. Paul, Minn., by the Minnesota Agricultural Experiment Station. This station submitted the following history of Anthony with application for registration:

> The original cross, from which the selection named Anthony was obtained, was made at University Farm in 1918. Selection was made during the segregating generations for resistance to stem rust and for desirable agronomic characters. The particular selection named Anthony was bulked after five generations had been studied by the individual plant method. After extensive rod-row trials, this selection was continued in field plat trials at the Central and Branch Stations, and named Anthony after it was decided to increase the variety for commercial distribution.

The variety was last selected in 1922 and application for registration was made in the name of the Minnesota Agricultural Experiment Station. It was first distributed to farmers in 1929. Anthony is a midseason white oat with equilateral panicles, resembling somewhat the Victory parent. Its superior qualities are high resistance to stem rust, high yield, stiff straw, and good quality. Anthony was tested in replicated rod rows at University Farm from 1922 to 1924, inclusive, and in fortieth-acre plats at University Farm, Waseca, Morris, and Crookston during the period from 1924 to 1928, inclusive,

in comparison with Victory which is recognized in Minnesota as a standard midseason variety. The annual and average acre yields obtained from these tests are shown in Table 4. Average data on stem-rust infection and lodging for the Anthony and Victory varieties are shown in Tables 5 and 6.

TABLE 4.—*Annual and average acre yields of oat varieties grown in replicated fortieth-acre plats at University Farm, St. Paul, Waseca, Morris, and Crookston, Minn., in the years indicated.*

| Location of station | Acre yield in bushels 1924 | 1925 | 1926 | 1927 | 1928 | Average |
|---|---|---|---|---|---|---|
| | | | Anthony (new) | | | |
| University Farm | 54.8 | 66.4 | 31.0 | 72.2 | 80.0 | 60.9 |
| Waseca | 91.1 | 100.4 | 48.8 | 50.0 | 102.8 | 78.6 |
| Morris | 74.2 | 96.1 | 54.3 | 67.2 | 62.7 | 70.9 |
| Crookston | 63.0 | 97.7 | 65.3 | 61.2 | 75.0 | 72 4 |
| Average | 70.8 | 90.2 | 49.9 | 62.7 | 80.1 | 70.7 |
| | | | Victory (standard) | | | |
| University Farm | 45.3 | 73.9 | 39.2 | 61.3 | 81.1 | 60.2 |
| Waseca | 74.4 | 86.5 | 47.1 | 29.9 | 91.2 | 65.8 |
| Morris | 69.5 | 90.2 | 55.2 | 47.1 | 44.4 | 61.3 |
| Crookston | 66.3 | 79.2 | 55.6 | 28.2 | 69.2 | 59.7 |
| Average | 63.9 | 82.5 | 49.3 | 41.6 | 71.5 | 61.8 |

TABLE 5.—*Relative percentage of stem-rust infection in the Anthony and Victory oat varieties when grown in fortieth-acre plats, 1924 to 1928, at stations named.*

| Location of station | Anthony | Victory |
|---|---|---|
| University Farm | 3 | 22 |
| Waseca | 1 | 42 |
| Morris | 13 | 35 |
| Crookston | 15 | 60 |
| Average | 8 | 40 |

TABLE 6.—*Lodging of the Anthony and Victory oat varieties at stations named.*

| Variety | University Farm, 1927–1928 % | Degree | Waseca 1926–1928 % | Degree | Morris 1924–1925 and 1927 % | Degree | Crookston % | Degree | Average % | Degree |
|---|---|---|---|---|---|---|---|---|---|---|
| Anthony (new) | 1 | 8 | 33 | 90 | 14 | 27 | 7 | 53 | 14 | 68 |
| Victory (standard) | 26 | 36 | 42 | 86 | 11 | 22 | 13 | 52 | 23 | 59 |

For additional information on Anthony see Minnesota (1).

## MIAMI, REG. No. 76

Miami (Ohio No. 6203 and C. I. No. 2245) was originated at the Ohio Agricultural Experiment Station, Wooster, as a pure-line selection from the Siberian variety. The original plant selection was made by C. G. Williams in 1906. It was first distributed to

farmers in 1912 and was named in 1922. Application for registration of Miami, including the following brief technical description, was submitted by L. E. Thatcher:

Plants midseason, midtall, midstiff. Ligule normal; nodes mostly downy; leaf margins smooth; panicle bushy (equilateral); rachis normal; spikelets pendant, 2 to 3-kerneled. Kernel white, midsized to large, mostly strongly awned, basalar connection solidified. Glume nerves 9 to 11; lemma nerves 7. Basal hairs of lemma few and short to none. Rachilla flat, short, hairs none.

Its superior qualities are high yield and high quality. Miami has been tested at Wooster for 20 years in field plats. The annual and average acre yields of Miami as compared with Siberian and Big Four, the parent and a standard variety, respectively, for the 5-year period from 1924 to 1928, inclusive, at Wooster, are shown in Table 7.

TABLE 7.—*Annual and average acre yields of Miami, Siberian, and Big Four oat varieties in plat experiments at Wooster, Ohio, for the years named.*

| Variety | Acre yield in bushels | | | | | |
|---|---|---|---|---|---|---|
| | 1924 | 1925 | 1926 | 1927 | 1928 | Average |
| Miami (new) | 83.7 | 57.1 | 88.0 | 88.8 | 59.1 | 75.3 |
| Siberian (parent) | 81.8 | 57.6 | 69.8 | 76.6 | 54.8 | 68.1 |
| Big Four (standard) | 81.6 | 59.6 | 91.7 | 71.0 | 65.3 | 73.8 |

Miami has become of considerable commercial importance in northern Ohio. For more complete information on Miami see Williams, *et al.* (6, p. 18).

## WAYNE, REG. No. 77

Wayne (Ohio Hybrid No. 9673 and C. I. No. 2567) was originated at the Ohio Agricultural Experiment Station, Wooster, as a selection from a hybrid. Unfortunately, the record of the parents used in this cross was lost, and consequently they are unknown. It was last selected in 1909 by C. G. Williams. Application for the registration of Wayne was made by L. E. Thatcher, who has submitted the following brief technical description of the variety:

Plants midseason to early, midtall, stiff. Ligule normal; nodes smooth; leaf margins smooth, panicle bushy (equilateral); rachis normal; spikelets pendant, 2, rarely 3-kerneled. Kernel white, midsized, awns mostly reduced, basalar connection solidified. Glume nerves 9 to 10, or occasionally 7 to 11; lemma nerves 7. Basal hairs of lemma none. Rachilla flat, short, hairs none.

The superior qualities of Wayne are high yield and high quality. The annual and average acre yields of Wayne as compared with Big Four, the standard variety, in the 5-year period from 1924 to 1928, inclusive, at Wooster, are shown in Table 8.

TABLE 8.—*Annual and average acre yields of Wayne and Big Four oat varieties in plat experiments at Wooster, Ohio, in the years indicated.*

| Variety | Acre yield in bushels | | | | | |
|---|---|---|---|---|---|---|
| | 1924 | 1925 | 1926 | 1927 | 1928 | Average |
| Wayne (new) | 86.5 | 62.1 | 94.8 | 101.1 | 68.1 | 82.5 |
| Big Four (standard) | 81.6 | 59.6 | 91.7 | 71.0 | 65.3 | 73.8 |

Owing to the fact that Wayne has been the highest-yielding variety for a 16-year period in the experiments at Wooster, the Ohio Agricultural Experiment Station is planning to distribute it to farmers of Ohio in 1930. For further information on Wayne see Ohio (2, p. 9).

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## NOTE

### RED TAG CERTIFIED ALFALFA SEED ADAPTED TO HAY PRODUCTION

The Tri-State Certification Conference, comprising the certifying agencies of Idaho, Montana, and Utah, in its third annual meeting at Blackfoot, Idaho, August 19 and 20, was confronted by the problem of sales resistance encountered in the handling of certified red tag alfalfa seed. Farmers in alfalfa seed-consuming sections were said to have an aversion for red tag based upon the belief that this seed was grade No. 2.

It was decided by the Conference that an investigation be made and information be published as to what certified red tag alfalfa seed really is. Accordingly, a review was made of all purity analyses and grade designations of Idaho certified Grimm alfalfa seed, performed in the state seed laboratory between the dates of June 30, 1927, and July 1, 1929. The entire poundage of seed represented by the samples analyzed and graded was taken into consideration.

The statements presented below show how the Idaho certified Grimm alfalfa seed graded during the seasons of 1927 and 1928 and also are indicative of the averages of impurity, sweet clover seed content, and discoloration which will be approximated in red tag seed during succeeding years.

"Idaho certified and sealed Grimm alfalfa seed is graded in the state seed laboratory by an official seed analyst and according to uniform standards specified by the certifying agencies of Idaho, Montana, and Utah. There are but two grades for certified seed, grade No. 1 and sample grade No. 2. There are two classes of No. 1 seed, blue tag and red tag. Bags of sample grade No. 2 are given yellow tags.

"The combined crops of Idaho certified alfalfa seed produced during the seasons of 1927 and 1928 graded 20.73% blue tag, 47.94% red tag, and 31.32% yellow tag, according to analyses made in the state seed laboratory. The predominating designation was red tag class of No. 1 seed, which many have presumed incorrectly to be No. 2 seed. The same analyses showed that all red tag seed averaged 20.43 sweet clover seeds per pound, or approximately 1/140 of 1%. The average discoloration was slightly over 7%, or approximately midway between the maximum tolerance for blue tag and that specified for red tag. The average of all red tag seed was slightly more than 99.2% pure alfalfa.

"Blue tag is extra No. 1 seed and is utilized extensively as foundation stock for seed-producing purposes because of its freedom from sweet clover. Red tag is No. 1 seed suitable for hay-producing purposes. Both are identical as to hardiness under severe climatic conditions and differ only in that the requirements for red tag allow one-half of 1% more impurity, one-sixteenth of 1% more sweet clover seed, and 5% more discolored seed than is allowed in blue tag seed. Impurity consists largely of broken seeds. Sweet clover will disappear from fields cut for hay within two years after planting. Slightly discolored seeds germinate almost as readily as bright seed.

Slight discoloration in fresh Idaho certified alfalfa seed indicates that it was produced under severe climatic conditions.

"Compare the figures given above and it will be found that red tag seed, which comprised almost one-half of the combined Idaho certified alfalfa seed crops for 1927 and 1928, (1) could have had one-half of 1% more impurity than blue tag, but had three-tenths of 1% instead; that (2) it could have had one-sixteenth of 1% more sweet clover than blue tag, but had 1/140 of 1% instead; and that (3) it could have had 5% more discoloration than blue tag, but had about 2.5% instead.

"Idaho red tag certified alfalfa seed is adapted to hay production purposes. Blue tag is fancy seed. A red colored certification tag is not a danger sign. Insist on red tag or better."—J. D. REMSBERG, JR., *Field Agronomist and Seed Commissioner, State of Idaho, Extension Service, Boise, Idaho.*

## FELLOWS ELECT, 1929

### WILLIAM L. SLATE

WILLIAM L. SLATE was born in Norwalk, Ohio, in 1888. He was educated in the Ohio schools and received his Bachelor of Science degree from the Ohio State University in 1909. From 1909 to 1911 he was assistant agronomist for the New Hampshire Experiment Station, and from 1911 to 1913 was Associate Professor of Agronomy at the University of Maine. He became agronomist at the Storrs Agricultural Experiment Station in 1913, and since 1923 has had the added duty of Director of the Connecticut Agricultural Experiment Station at New Haven. He was one of the founders of the New England Section of the American Society of Agronomy, and has labored constantly toward its development. He was at one time president of this Section.

Director Slate made worthy contributions to agronomy through his studies on the causes of deterioration of seed potatoes, corn varieties for New England with especial reference to maturity, pasture improvement, etc. He has always been a loyal and active member in our Society, taking an active part in many of our programs.

### HOMER LEROY SHANTZ

HOMER LEROY SHANTZ, was born in Kent County, Michigan, in 1876. He received his Bachelor's degree from Colorado College in 1901, and his Doctor's degree from the University of Nebraska in 1905. He was an instructor in botany and zoology at the Colorado College in 1902, and in botany at the University of Nebraska in 1903 and 1904, holding a similar position immediately following at Missouri, and then at Louisiana, where, in 1907, he became Professor of Botany and Bacteriology.

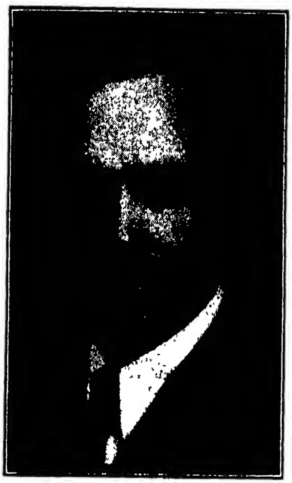
In 1908, he entered the U. S. Department of Agriculture as plant physiologist, where he made notable contributions on native vegetation as an index to environmental conditions and the agricultural value of land, and the wilting point of plants as an index to the physical character of the soil. He later was in charge of the investigations of plant geography in its relation to plant industry.

In 1926, he left the federal department and accepted the chairmanship of the Botany Department of the University of Illinois, leaving there in 1928 to

become President of the University of Arizona, which position he now holds. Dr. Shantz is a member of a great many professional organizations and honorary fraternities. He has long been a member of the Committee on Terminology of this Society. He has made numerous and noteworthy contributions to scientific literature. He has made extensive studies of the plant geography of the continent of Africa.

## EDWARD FRANKLIN GAINES

EDWARD FRANKLIN GAINES was born at Avalon, Missouri, in 1886. He received his Bachelor of Science degree from Washington State College in 1911, his Master's degree in 1913, and the Doctor of Science degree from Harvard University in 1921. He entered the employ of the Washington State College in 1911 as assistant cerealist, and has made steady advancement since that time.



Dr. Gaines has rendered outstanding service to the small grain industry of the Pacific Northwest. He developed and distributed Triplet wheat, a high yielding variety now extensively grown throughout that territory. He has also produced two smut-resistant varieties of wheat, Ridit and Albit, that are of great promise. He has made valuable contributions through his studies of smut inheritance and through his recent discoveries of new and different physiologic forms of smut.

Dr. Gaines has always been an active and faithful member of our Society. He has rendered excellent service to it, both through his several years as an officer of the Society and his long membership on importamt committees.

# AGRONOMIC AFFAIRS

## MINUTES OF THE TWENTY-SECOND ANNUAL MEETING

The meeting was called to order by President M. J. Funchess at 9:30 A.M., on Thursday, November 14, at the Stevens Hotel, Chicago, Ill. Over 280 members and visitors registered and more than 300 were present at the sessions.

The following committees were appointed: *Nominating*—R. W. Thatcher, chairman, M. F. Miller, and C. A. Mooers. *Auditing*—J. R. Fain, chairman, and M. M. McCool. *Resolutions*—S. B. Haskell, chairman, C. G. Williams, and George Roberts.

The program which had been arranged was presented (page 1208).

The annual dinner was held at 6:30 P.M. at the Stevens, 159 attending, President M. J. Funchess delivering the retiring presidential address (page 1117). The annual business meeting was then held.

### FELLOWS

Vice-President W. W. Burr presented the Fellows Elect and read a short biographical sketch of each (pages 1183–1184). President H. L. Shantz, Director W. L. Slate, and Dr. E. F. Gaines were the men thus honored. Diplomas were presented. Dr. Gaines was unable to attend the meeting.

### CHILEAN NITRATE OF SODA NITROGEN RESEARCH AWARDS

Dr. W. P. Kelley, chariman of the committee, presented the winners of the award as follows:

Dr. P. L. Gainey of Kansas for his researches on nitrogen fixation by Azotobacter.

Dr. S. A. Waksman for his researches on the biological decomposition of organic materials in soils.

Prof. C. A. Mooers for his investigations on the time and rate of application of nitrogen fertilizers.

Diplomas were presented and it was announced that the three men would share equally in the five thousand dollars awarded annually.

### REMARKS BY THE CHILEAN AMBASSADOR

The Chilean Ambassador to the United States being present was called on by President Funchess and responded as follows:

Mr. President and Members of the American Society of Agronomy:

It is my privilege and pleasure to convey to you the cordial greetings and good wishes of my Government, which has asked me to represent it on this occasion. Our countries, yours and mine, have many parallels in their political, economic, and social lives. Although our systems of agriculture have been developed to meet different conditions, our agricultural workers have much in common with yours. We have closely followed the progress made by your farmers in lowering costs of production and in improving the quality of their products. We hope that their present efforts to develop an efficient marketing system will meet with the same degree of success that they have had in these other fields of farm enterprise.

Next year, 1930, marks an event of significance in the commercial relations of our respective countries. One hundred years ago the first shipment of nitrate of soda was brought to the United States. While this is an event of importance

in the history of agriculture, it has even greater significance in international relations. Since then the nitrogen question has assumed paramount importance, and the industry has steadily advanced, actuated always by the desire to increase the measure of its service to the agriculture of the world. In its early history the Chilean Nitrate industry was largely Chilean and British in character. Today American capital comprises nearly one-half the total investment. With this development, so fortunate for the stability and prosperity of my country, has come the introduction on a wide scale of modern industrial and production methods, greater efficiency in our operations and lower prices to consumers of our products. Today, three-quarters of a billion dollars of American capital are invested in Chilean enterprises.

In behalf of my government and the nitrate industry, I extend my heartiest congratulations to the distinguished scientists who have been honored by this Society for their accomplishments in nitrogen research. These men have left an indelible impression upon the pages of soil science. The results of research in nitrogen problems add much to our understanding of those hidden secrets of nature which man has ever sought. I hope that this recognition will serve to focus the searchlight of science on more of the nitrogen problems that confront modern agriculture.

## WINNING COUNTY AGENTS

Dr. F. J. Alway of the judging committee announced the winners in the annual contest conducted by the National Fertilizer Association for the best soil fertility programs submitted by county agents. The winning agents were presented to the Society.

## OFFICERS REPORTS

J. D. Luckett, editor, presented his report, which, upon motion, was accepted.

### REPORT OF THE EDITOR

This report will deal largely with agronomic relief, particularly with regard to the disposition of surpluses of literature produced by members of the American Society of Agronomy. While we do not contemplate resorting to debentures or other forms of subsidy, we hope to offer you a program that will afford at least some degree of relief without stimulating production unduly.

But first we would review very briefly the make-up of the 1929 volume of the JOURNAL and the prospects for 1930. Volume 21 will be about average in size and content, as compared with its immediate predecessors. When the December number comes from the press, there will have been published in the current volume 41 symposia papers, 73 contributed articles, 7 book reviews, and 11 notes, in addition to numerous "news" items and matters of agronomic interest. Fifteen papers have been returned to the authors during the course of the year, and 33 accepted contributions were on hand on November 1. This makes a total of 181 papers to pass through the editor's hands since his last report.

With the completion of Volume 21, all papers accepted prior to May 15 will have been published. At this time last year we were able to report that the publication schedule was only three months behind, i.e., that all papers accepted prior to October 1, 1928, were published in the 1928 volume. We shall have more to say later in this report about this increasing spread in time between acceptance and publication and shall offer some suggestions looking to relief in this direction.

We note a gratifying response on the part of contributors to the JOURNAL to our request for more and still more condensation of manuscripts, but we are confident, that even yet, many papers sent to us could be substantially curtailed without detracting in the least from their effectiveness. We hope that such suggestions for curtailment as we see opportunities to make from time to time will be taken in the spirit intended—to make our JOURNAL pages go as far as they possibly can in serving the greatest number of contributors at the earliest possible opportunity. At this point a suggestion made by a member of the Editorial Advisory Committee might well be mentioned as a possible means of effecting a considerable saving in space, although we do not offer it as a definite editorial policy for the JOURNAL at this time. The suggestion is that in presenting data only the maximums, minimums, and means, with their probable errors, be reported, thus obviating the necessity of many lengthy tables. Incidentally, authors would do well to keep in mind that each page of tabular matter in the JOURNAL represents more than a year's subscription to the JOURNAL, thus do the mounting costs of printing absorb our resources.

Early in 1929, the cumulative author and subject index of the first 20 volumes of the JOURNAL made its appearance. The modest price of fifty cents was arrived at as a fair remuneration to the Society for the publication of the index and copies may be had from the Secretary upon remittance of that sum. It is intended, in the future, to build up a cumulative index as additional volumes are completed so that at any desired interval, say of five or ten years, the cumulative material might be published as part of the current volume for the year.

We mentioned in our last report that advertising in a journal such as ours partakes largely of the nature of goodwill advertising. We are pleased to report that we continue to enjoy the good will of most of our old advertisers, and we urge again a reciprocity of sentiment between the readers of the JOURNAL and our advertisers by the simple words, "I saw it in the JOURNAL OF AGRONOMY." Seriously, though, we should have double the amount of advertising in our JOURNAL that we now have. The JOURNAL has a circulation that compares favorably with many scientific publications that enjoy greater patronage. The difficulty, we believe, lies largely in the feeling on the part of advertisers that on the whole our readers are not potential buyers, despite our efforts to persuade them to the contrary. The potential buying power of our institutions, however, represents a very respectable figure, and a little home missionary work on the part of members of the Society with representatives of laboratory supply houses, book publishers, and others who cater to agronomic needs might bear fruit.

The mention of home mission fields reminds us in passing that there will be an opportunity in 1930 for certain members of the Society to do some very effective foreign missionary work for the JOURNAL. We refer to the International Soil Congress to be held in Russia next year. We hope that each member of the Society who attends that Congress may feel the call to say a word for the JOURNAL to his foreign colleagues whenever the opportunity presents itself. We undoubtedly could increase our circulation abroad if the JOURNAL were better known.

It is a pleasure to acknowledge our indebtedness to the several Correspondents scattered about the country who have faithfully kept us advised of items of interest to agronomists and who have made possible the section on "News Items" which we regard as well worth the space it takes. We solicit their continued support.

We ventured to mention in our last report what we regarded as a trend during the past two years toward an increasing number of soils papers as compared with

the number of crops papers offered for publication in the JOURNAL. Our calculations have been rudely upset this year by an influx of crop papers that leaves the count for 1929 two to one in favor of crop subjects. Thus we have learned to leave well enough alone and have marked the project "closed."

And now to set forth briefly certain changes in the editorial policies of the JOURNAL which we propose in the hope that, in due time, they will expedite the publication of papers with a reduction in the interval of time between acceptance and publication, and of equal importance just at present, attain this end at a cost well within the means of the Society. It should be stated that these recommendations have the endorsement of the Editorial Advisory Committee and are presented here with the approval of the Executive Committee.

1. *The discontinuance of the publication of symposia as complete units.*—With a full appreciation of the advantages to be gained from publishing symposia papers as complete units, nevertheless, we are continually embarrassed by the delays in publishing contributed articles due to the space preempted by symposia, as witness the 41 symposia papers published in the current volume. Acting on authority vested in the Editor some time ago, we propose, therefore, to place symposia papers on the same footing as other papers offered for publication in the JOURNAL, to stand or fall on their individual merits and to take their turn in the publication schedule. The Editor has not hardened his heart altogether to the symposia idea and is ready to give a hearing to symposia leaders who feel that some particular topic is of such general interest to the readers of the JOURNAL that it merits special consideration. However, no effort will be made in the future to assemble symposia papers for publication as has been done in the past.

2. *A fixed size for the* JOURNAL.—The early numbers of the JOURNAL each year usually wax fat, while with advancing months and receding resources the pages drop off to a quite noticeable degree, although for the past few years the completed volumes run fairly uniform in size. Believing that a fixed number of pages per issue will insure a more even flow of material and that it will have certain advantages from a business point of view, it is recommended that the Treasurer and the Editor determine in advance the number of pages to be included within each new volume, with allowance for special matter that may be published in the December issue, apportioning the pages over the twelve issues of the JOURNAL. Probably for 1930 this allowance will be 96 pages per issue.

3. *Reduction in number of free reprints.*—We regret to make this suggestion, but we have felt for some time that the practice of supplying fifty free reprints of each article published in the JOURNAL was of questionable wisdom for a journal sold at so low a figure as ours. In 1928, it cost the Society $708.41 to supply the fifty free reprints that have gone to each author. The costs in 1929 are already well above $500 with the November and December issues yet to be accounted for. We propose, therefore, to reduce the number of free reprints to twenty-five, effective with Volume 22. Of course, additional reprints will be available in any quantity desired, as in the past.

4. *Illustrations.*—The cost of supplying half-tones and zinc etchings for illustrating articles in the JOURNAL adds very substantially to the overhead, and we feel that we must now scrutinize illustrative matter even more closely than we have in the past. We shall be especially critical of photographs for half-tone reproduction, while graphs and line drawings, which in the opinion of the Editor aid materially in an understanding of the text, and especially where they can be substituted for tables and where the number required is not excessive, will be viewed with somewhat greater favor.

We would not leave you with the impression that the JOURNAL is in any sense in a precarious condition, but rather that adjustments to changing conditions are to be expected from time to time in any growing institution. We trust that the changes proposed here do not seem too drastic, especially in view of the demands on the finances and space of the JOURNAL. If the degree of relief anticipated is attained, we shall feel fully justified in setting the JOURNAL on this new course.

Finally, it is our privilege to acknowledge once more the moral support and the wise judgment of the several members of the Editorial Advisory Committee who have aided us so materially during the past year. Your JOURNAL is in safe hands so long as the members of this committee, who have so much at heart the best interests of the Society and of the JOURNAL, continue to guide its destinies.

We are sure that all will agree that our poor words can add little to the esteem in which you hold your energetic Secretary and your efficient Treasurer. The former has dealt most kindly with our numerous shortcomings and has interceded most effectively with the latter on our behalf in many instances during the past year. Thus, publicly, we delight to acknowledge to Dr. Brown our profound thanks and appreciation of his splendid cooperation with the editorial office.

## REPORT OF THE TREASURER

The Treasurer read his annual report which was received and referred to the Auditing Committee.

I beg to submit herewith the report of the Treasurer for the year November 1, 1928, to November 1, 1929:

| | |
|---|---|
| Balance, last report, general fund | $758.35 |
| Balance, last report, Lime Association fund | 147.20 |
| Total balance, last report | $905.55 |

### RECEIPTS, 1929

| | | |
|---|---|---|
| Dues, 1929 | $3,647.50 | |
| Dues, 1929 new | 625.00 | |
| Dues, 1928 | 15.00 | |
| Dues, 1930 | 5.00 | |
| Subscriptions, 1929 | 1,372.87 | |
| Subscriptions, 1929 new | 388.88 | |
| Subscriptions, 1928 | 219.08 | |
| Subscriptions, 1930 | 42.12 | |
| Advertising income | 1,231.43 | |
| Reprints sold | 908.39 | |
| Journals sold | 530.80 | |
| Index account | 71.00 | |
| | | $9,057.07 |
| Total receipts | $9,057.07 | |
| Total income 1929 | | $9,962.62 |

### DISBURSEMENTS, 1929

| | | |
|---|---|---|
| Printing the JOURNAL—reprints, etchings, mailing, etc. (10 issues Oct. 1928–August 1929) | $7,598.22 | |
| Salary, Business Mgr. (11 months) | 687.50 | |
| Printing (programs, stationery, etc.) | 166.50 | |
| Postage (Secretary and Business Mgr.) | 109.75 | |
| Freight, express and drayage | 30.49 | |
| Refunds on accounts, checks returned, etc | 61.50 | |
| Printing index (including $7 for mailing envelopes) | 269.59 | |
| Miscellaneous (supplies, expenses of annual meeting, badges, telegrams and certificates, etc.) | 314.32 | |
| | | $9,237.87 |
| Total disbursements | $9,237.87 | |
| Balance on hand | | $ 724.75 |
| Balance, Lime Association Fund | $ 147.20 | |
| Balance, general fund | 577.55 | |
| Total balance | | $724.75 |
| Total income | $9,962.62 | |
| Total disbursements | 9,237.87 | |
| Balance | $ 724.75 | |

Respectfully submitted,
P. E. BROWN, *Treasurer.*

Dr. J. R. Fain reported that the Auditing Committee had examined the books and vouchers of the Treasurer and found them correct. Upon motion the report was adopted.

Dr. A. G. McCall reported as Assistant Treasurer in charge of the funds collected and utilized in connection with the First International Congress of Soil Science. The report, which follows, was adopted.

### AMERICAN SOCIETY OF AGRONOMY IN ACCOUNT WITH THE EXECUTIVE COMMITTEE OF THE FIRST INTERNATIONAL CONGRESS OF SOIL SCIENCE NOV. 1, 1928, TO NOV. 1, 1929

#### RECEIPTS

| | | |
|---|---|---|
| Sale of Proceedings First International Congress of Soil Science | $2,034.00 | |
| Membership dues and initiation fees for International Society of Soil Science | 900.40 | |
| Abstracts and miscellaneous | 39.82 | |
| Interest on savings bank account (First National Bank of Hyattsville, Hyattsville, Md.) | 138.16 | |
| | $3,112.38 | |
| Balance on hand, November 1, 1928 | 7,621.30 | |
| | | $10,733.68 |

#### EXPENDITURES

| | | |
|---|---|---|
| Publishing Proceedings of the First International Congress of Soil Science—printing Vol. IV (The Rumford Press, Concord, N. H.) | $4,518.83 | |
| Printing Vol V | 1,533.45 | |
| Typing MSS preparation to use in Vol. V | 3.75 | |
| Photographs for use in Vol. V | 18.00 | |
| Printing of labels for distribution of Proceedings | 18.00 | |
| Distribution and mailing of Proceedings by The Rumford Press, Concord, N. H | 796.05 | |
| | | 6,888.08 |

| | | | |
|---|---|---|---|
| Contribution toward publication of Soil Research | | $ 500.00 | |
| Contribution toward publication of the Soil Map of Europe by Prof. Stremme | | 500.00 | |
| Office salary | | 447.50 | |
| Postage ($1.59 of this postage fund of $75 was used to pay small items in cash for express charges included in item of "expressage" below) | | 73.42 | |
| Telegraph | | 3.10 | |
| Expressage | | 23.22 | |
| Stationery for office use | | 3.41 | |
| Refund on overpayment of dues Dr. Senstius | $3.00 | | |
| Refund on overpayment of dues J. E. Chapman | 2.60 | | |
| Refund on overpayment Proceedings for the Rhode Island Experiment Station | 4.00 | 9.60 | |
| Membership dues transmitted to Dr. D. J. Hissink* | | 904.60 | |
| Printing membership cards for office records | | 4.00 | |
| Multigraphing letters to membership American Sec. | | 8.10 | |
| Premium on bond of A. G. McCall | | 5.00 | |
| | | $9,370.03 | |
| Balance on hand in bank Nov. 1, 1929 | $1,368.65 | | |
| Less outstanding check | 5.00 | $1,363.65 | $10,733.68 |

Submitted by,
A. G. McCall,
*Exec. Secretary, American Organizing Committee.*

*Total dues received Nov. 1, 1928, to Nov. 1, 1929, as per receipts, $900.40; adjustment made with Dr. Hissink, $4.20; to agree with his records which show $904.60.

## REPORT OF THE SECRETARY

The report of the Secretary was then read and upon motion was accepted.

| | | | |
|---|---|---|---|
| Membership changes, 1928–1929: | | | |
| Membership last report | | | 823 |
| New members, 1929 | | 133 | |
| Reinstated members | | 63 | |
| Total increase | | 196 | |
| Dropped for non-payment of dues | 104 | | |
| Resigned | 9 | | |
| Total decrease | 113 | | |
| Net increase | | 83 | |
| Membership, Nov. 1, 1929 | | | 906 |
| Subscriptions: | | | |
| Subscriptions, last report | | | 387 |
| New subscriptions | | 114 | |
| Subscriptions dropped | | 47 | |
| Net increase | | | 67 |
| Subscriptions, Nov. 1, 1929 | | | 454 |

Membership by States and Countries:

| | Members | Subscriptions | | Members | Subscriptions |
|---|---|---|---|---|---|
| Alabama | 21 | 1 | Alaska | 4 | 1 |
| Arizona | 9 | 1 | Argentina | 8 | 9 |
| Arkansas | 6 | 3 | Australia | 5 | 18 |
| California | 26 | 5 | Bolivia | 1 | 0 |
| Colorado | 8 | 4 | Brazil | 1 | 0 |
| Connecticut | 11 | 4 | British West Indies | 1 | 2 |
| Delaware | 3 | 2 | Canada | 28 | 34 |
| District of Columbia | 70 | 3 | Ceylon | 0 | 2 |
| Florida | 12 | 3 | China | 7 | 9 |
| Georgia | 21 | 3 | Cuba | 3 | 0 |
| Idaho | 8 | 1 | Czecho-Slovakia | 0 | 1 |
| Illinois | 43 | 14 | Denmark | 1 | 1 |
| Indiana | 24 | 2 | Dominican Republic | 0 | 1 |
| Iowa | 35 | 6 | Dutch East Indies | 0 | 1 |
| Kansas | 30 | 2 | Egypt | 4 | 1 |
| Kentucky | 9 | 2 | England | 3 | 9 |
| Louisiana | 10 | 2 | Estonia | 0 | 1 |
| Maine | 5 | 1 | Fed. Malay States | 0 | 2 |
| Maryland | 12 | 3 | Fiji | 0 | 1 |
| Massachusetts | 17 | 6 | Finland | 0 | 3 |
| Michigan | 19 | 3 | France | 0 | 5 |
| Minnesota | 17 | 5 | Germany | 4 | 6 |
| Mississippi | 8 | 4 | Haiti | 1 | 0 |
| Missouri | 16 | 5 | Hawaii | 11 | 10 |
| Montana | 10 | 2 | Holland | 0 | 1 |
| Nebraska | 17 | 3 | Honduras | 2 | 1 |
| Nevada | 1 | 2 | India | 4 | 12 |
| New Hampshire | 2 | 1 | Ireland | 0 | 2 |
| New Jersey | 12 | 4 | Italy | 1 | 5 |
| New Mexico | 4 | 2 | Japan | 6 | 60 |
| New York | 43 | 25 | Jugoslavia | 1 | 1 |
| North Carolina | 16 | 2 | Latvia | 0 | 2 |
| North Dakota | 14 | 1 | Mesopotamia | 1 | 1 |
| Ohio | 33 | 4 | Mexico | 2 | 2 |
| Oklahoma | 15 | 4 | Norway | 0 | 2 |
| Oregon | 8 | 3 | Peru | 2 | 2 |
| Pennsylvania | 16 | 4 | Philippine Islands | 3 | 3 |
| Rhode Island | 4 | 0 | Poland | 1 | 1 |
| South Carolina | 10 | 1 | Porto Rico | 0 | 3 |
| South Dakota | 7 | 1 | Russia (U.S.S.R.) | 4 | 36 |
| Tennessee | 8 | 2 | Salvador | 0 | 1 |
| Texas | 35 | 4 | Scotland | 0 | 2 |
| Utah | 9 | 6 | Siam | 0 | 1 |
| Vermont | 3 | 1 | Southern Rhodesia | 0 | 1 |
| Virginia | 19 | 2 | South Wales | 0 | 1 |
| Washington | 12 | 4 | Sweden | 2 | 3 |
| West Virginia | 7 | 1 | Switzerland | 1 | 0 |
| Wisconsin | 28 | 2 | Turkey | 1 | 0 |
| Wyoming | 4 | 1 | Uruguay | 0 | 1 |
| | | | Virgin Islands | 1 | 0 |
| Africa | 14 | 25 | Wales | 1 | 1 |
| Total | | | | 906 | 454 |

Members by Years:

| | |
|---|---|
| 1908 Charter | 36 |
| 1908 | 10 |
| 1909 | 5 |
| 1910 | 16 |
| 1911 | 23 |
| 1912 | 17 |
| 1913 | 20 |
| 1914 | 14 |
| 1915 | 29 |
| 1916 | 52 |
| 1917 | 23 |
| 1918 | 17 |
| 1919 | 13 |
| 1920 | 25 |
| 1921 | 38 |
| 1922 | 36 |
| 1923 | 24 |
| 1924 | 37 |
| 1925 | 80 |
| 1926 | 77 |
| 1927 | 81 |
| 1928 | 98 |
| 1929 | 135 |
| Total | 906 |

Total Membership by Years:

| | | | | | |
|---|---|---|---|---|---|
| 1908 | 121 | 1915 | 471 | 1922 | 643* |
| 1909 | 129 | 1916 | 586 | 1923 | 561 |
| 1910 | 176 | 1917 | 652 | 1924 | 577 |
| 1911 | 236 | 1918 | 509 | 1925 | 646 |
| 1912 | 295 | 1919 | 473 | 1926 | 700 |
| 1913 | 349 | 1920 | 436 | 1927 | 767 |
| 1914 | 397 | 1921 | 592 | 1928 | 823 |
| | | | | 1929 | 906 |

*In 1922 the dues were increased to five dollars.

Respectfully submitted,
P. E. Brown, *Secretary.*

## COMMITTEE REPORTS

Dr. C. R. Ball, chairman, presented the report of the Committee on Terminology, which upon motion was accepted.

### TERMINOLOGY

In its last annual report your Committee discussed the growing use of privative verbs formed with the prefix "de," meaning "to remove" or "to deprive of" the article, organ, substance, character, or quality named by the nounal root. They discussed also the use of the past participle ending in "ed," as, for instance, "hulled," with the meaning "to possess" or "to provide" the thing named. In the report was given also a list of 20 infinitives (out of some two or three thousand infinitives and other forms) in which the infinitive has the meaning "to remove" or "to deprive of" instead of "to provide" or "to possess." In 12 cases out of these 20, the infinitives have both meanings. To avoid the frequent current confusions, it was suggested that the use of these 20 forms, more or less colloquial in origin, in the sense of "to remove" or "to deprive of," might well be abandoned and the prefix "de" applied to the root when this meaning was intended. The meaning of such verbs always is clear.

Webster's New International Dictionary gives warrant for their formation and use in the following words, "In English words not derived directly from French or Latin, *de-* usually has this sense [depriving or ridding from: ORB] and is used at will to form verbs (and their derivations) having an annulling or privative force."

During the year good progress has been made on the manuscript of a paper on this subject. Of the three sections into which it is divided, the literature has been quite thoroughly reviewed for two. The manuscript of the first section, dealing with principles and trends, is in second draft. That of the second section, dealing with usage in cereal crops, is in practically final draft. The manuscript of the third section, dealing with usage in the discussion of clovers and other forage crops, has not yet been prepared, though advance has been made in the study of the literature.

Not the least interesting part of the year's work has been the scanning of current literature for indications of the trend in usage of such terms. The accumulation of literature references has been greatly increased.

A year ago there was given a list containing the following 14 privative infinitives with the prefix "de" and not found specifically in either the International or Standard Dictionaries:

| | | | |
|---|---|---|---|
| debitter | deglume | delouse | deseed |
| debunk | dehull | delustered | desprout |
| defat | dehusk | demouse | detail |
| defruit | delead | | |

During the year the following 8 additional examples have been noted in popular and technical literature, namely,

| | | | |
|---|---|---|---|
| decode | de-English | de-rate | dewool |
| de-egg | demode | desucker | dethorn |

In addition, there has been an increase in use of some of those noted in the list last year. For example, the verb "debunk" is in common use by both humorous and serious writers. Numerous additional examples of the use of "dehull" have been noted during the year, and the same is true of "delouse," "deluster," and "desucker." There can be little doubt as to the trend of the times in this regard.

Prof. Charles F. Shaw, a member of this Committee and representing soils, has submitted to the JOURNAL of our Society the manuscript of a paper entitled "Is Pedology Soil Science?" In this, he points out that while the term "pedology" has been used to mean soil science, the term has come into rather common use with the meaning "child study," although the original Greek root was "paedo" and not "pedo." Because of the generally accepted meaning of this term, Prof. Shaw recommends the use of the term "edaphology" with the meaning "soil science." The term "edaphology" was suggested by Ball and Piper, then members of your Committee on Terminology, as early as 1910. It later was used by them in their respective capacities as editor for agronomy in *Botanical Abstracts* and in *Biological Abstracts*.

HOMER L. SHANTZ
CHARLES F. SHAW
CARLETON R. BALL, *Chairman.*

Dr. T. A. Kiesselbach, chairman, read the report of the Committee on Standardization of Field Experiments, which was accepted.

## STANDARDIZATION OF FIELD EXPERIMENTS

Your committee has had one formal meeting during the year to consider further work that might be done. It is believed that the official standards of experimental procedure which have been adopted by the Society and the various additions which have been made to the bibliography would be more effective if brought together into a single unified report.

In view of more recent contributions to the technic of field experiments and their interpretations, it seems probable that a number of additions and possibly some revisions might be offered for incorporation into the official standards, provided the Society approves of such action.

The committee commends the members of the Society for their continued investigation of experimental methods since only through comparative studies of this type is it possible to establish the most desirable procedure.

R. J. GARBER
H. H. LOVE
M. M. MCCOOL
C. A. MOOERS
T. A. KIESSELBACH, *Chairman*

R. G. Wiggans presented the report of the Committee on Varietal Standardization, which, upon motion, was accepted.

## VARIETAL STANDARDIZATION

The work of the Varietal Standardization Committee has been continued along the same line as in previous years. A provisional plan for the registration of cotton was sent to a committee of southern agronomists and was presented at a meeting of southern agricultural workers. They requested more time to study the question before registration was undertaken. The subject of registration of sorghum varieties has received some consideration and a committee is at present working on the problem.

Reports of the sub-committees on wheat, oats, and corn have been considered by the Varietal Standardization Committee and suggestions have been made regarding these reports. The sub-committee on corn registration has submitted a sound and practical plan for the registration of selfed strains of corn which has been approved by the Varietal Standardization Committee for submission to the Society. There is some doubt of the wisdom of the statement that "no hybrid combinations as such are to be eligible to registry." The original plan of this committee submitted to the Society before the corn registration committee was appointed, called for the registration of $F_1$ or double crosses of corn on the basis of their merit for commercial utilization and at the same time the registration of the selfed lines used to produce the hybrids. Other crops are being registered on the basis of merit as demonstrated in comparative trials at a state or federal experiment station and it still seems desirable to some members of our committee to make corn hybrids eligible to registration. Respectfully submitted,

R. G. WIGGANS
J. H. PARKER
E. F. GAINES
L. H. NEWMAN
H. K. HAYES, *Chairman.*

F. D. Richey, Chairman, presented the report of the Sub-committee on the Registration of Corn, and, upon motion, the report was accepted.

## REGISTRATION OF CORN VARIETIES

In its report for 1926 the Society's Committee on Varietal Standardization made the following recommendation[1]:

"The cooperative program under the Purnell Fund for the improvement of corn by the method of selection in self-fertilized lines and their recombination leads to the belief that in the very near future a system of registration of selfed lines of corn which are used in hybrid combinations and of the hybrid combinations themselves will be desirable. It is proposed, therefore, that (1) the American Society of Agronomy authorize the registration of $F_1$ hybrid combinations, i.e., single or double crosses, and of selfed lines of corn; (2) that the method of determination of the value of hybrid combinations be similar to that adopted for the small grains, with the reservation that such hybrid combinations must be produced from selfed strains which are practically homozygous and which have been selfed for at least five generations; and (3) that the selfed strains used in these hybrid combinations be registered at the same time."

Pursuant to this recommendation, a sub-committee on varietal registration of corn was appointed in December, 1926. At the 1927 meeting, this committee reported[2] that they felt that, though it might be desirable to provide for registration of selfed lines of corn, there were too few lines about which anything was known definitely at that time to warrant beginning such registration. This same committee was continued in 1928, but as its opinion had not changed no formal report was made.

The present committee doubts whether many inbred strains of corn suitable for registering are available even now. At the same time, crosses between inbred strains are coming into prominence commercially, and the International Crop Improvement Association has appointed a committee to draw up plans for the certification of hybrid corn. These facts make it desirable for this Society to provide definitely for the registration of inbred strains of corn, even though the requirements are such as to preclude immediate registry of many such inbred lines.

The sub-committee on registration of corn accordingly recommends the following regulations to govern registration of inbred strains of corn, no open-pollinated varieties and no hybrid combinations, as such, to be eligible to registry.

### ELIGIBILITY

1. Evidence that a strain is homozygous for some definite character of major plant breeding importance shall entitle such strain to registration, but no strain shall be registered under this provision unless it excels other strains to a degree that makes it a recognized source for the character in question.

2. Other strains shall be eligible to registration if they are sufficiently homozygous reasonably to insure their breeding true for those characteristics that make them of outstanding value, either as inbred strains, or as parent strains in $F_1$ crosses or double crosses with other registered strains.

a. To be eligible to registration, a strain must be uniform with respect to its important agronomic characters, and, in addition, have been produced as the result of self-pollination, or of back-pollination with a strain which would qualify for registration under this section, through not less than six successive generations: Provided, that two generations of sib pollination (pollen from another plant from seed from the same ear) may be substituted for each of the last two (fifth and sixth) generations of self pollination. Seed of the generations later than those specified above shall be propagated by pollination within the strain.

[1]Jour. Amer. Soc. Agron., 18:1144. 1926.
[2]Jour. Amer. Soc. Agron., 19:1129–1130. 1927.

b. Evidence of the value of strains shall consist of data showing that the strain or the cross has produced a yield or had some other important performance record significantly better than that of a recognized standard variety or varieties with which it has been compared during a period of not less than three years in adequate replicated experiments under federal or state supervision.

### APPLICATION FOR THE REGISTRY OF AN INBRED STRAIN OF CORN

1. Name of applicant.
2. Breeder or breeders and institution or institutions developing.
3. Because of its value as an inbred strain or as a parent in crosses.
4. Designation. Include here the pedigree or other designation by which the inbred strain may be identified in the records of the institution or institutions developing same.
5. Parent variety, strain, or cross and its source or adaptation.
6. Years in which the first four successive generations of selfpollination or backpollination occurred.
7. Subsequent breeding: Years in which the systems of mating stated were followed.
8. Superior characters of the strain, as such, on which eligibility to registration is claimed.
9. Crossed combinations on the performance of which eligibility to registration is claimed.
10. Superior characters of these crosses.
11. Are these crosses being used commercially?
12. Methods of comparison with a standard: Location, sizes of plats, numbers of replications, etc.
13. Performance record:

| Year | 19— | 19— | 19— | 19— | 19— | Average |
|---|---|---|---|---|---|---|
| Generations inbred* | | | | | | |
| Strain or cross standard | | | | | | |
| Difference. | | | | | | |

*Before comparison, if an inbred; if a cross, before the crossbred seed used was produced.

### DESCRIPTION OF INBRED STRAIN ..........................................

(Use the designation given under 2 of application.)

(This description should represent the mode for the strain as grown under reasonably favorable conditions.)

1. ............days to silking when grown at..........................................
2. ............days to maturity when grown at ..........................................
3. Height of plant, ........ feet.
4. Height of upper ear, ........... feet.
5. Chlorophyll development:
6. Husk length relative to ear length (+, o, —).
7. Ear length, ............cm; circumference, 3 cm from butt, ............cm; circumference, 3 cm from tip ............cm; weight ...........grams; ..........kernel rows.
8. Kernels:
   Pericarp: Clear; red; red, clear at crown; ..........................................
   Aleurone: Clear; ..........................................colored.

Endosperm: Yellow; white; white cap.
Flour; dent; flint; pop; waxy; sweet.
(Indentation: Flinty; dimpled; creased; pinched, beaked.)
Length.............mm; width.............mm; thickness...................mm.
Weight per 1,000, .................. grams.

9. Cobs: Red; white; . .. ...... . . ..... . . . .. ..
10. Other characters:
    Virtues:
    Neutral:
    Faults:

REGISTRATION

Consideration of the application, registration, and publication thereof shall proceed as outlined for the registration of wheat, oats, and barley in the JOURNAL OF THE AMERICAN SOCIETY OF AGRONOMY, Vol. 15: 28–529. 1923.

The registration certificate and published notice, however, should state the reason for registration, i.e., whether because of value as an inbred or in crosses, and, if the latter, the particular combination on the basis of which registration was approved also should be stated. The following form is suggested:

Improved Cereal Varieties

(Designation)

The inbred strain of corn.. . . .. . . . .... . . . .......... . . . .. ... ...... ..
selected by . .. . . ...... ... . . .. . . . ... . . . .. . ..... ... ... .

Accepted by the Sub-committee on Registration of Corn, this ... ............ ........ day of . .... ..... . . . , 19 .., under Registration Number . ..... .; Because of its value (as an inbred line, or in the cross: Registered Strains Numbers, .. ....... .... . . ........ ... .... . . . ..... . . . . . . .. ....... . .. .. .. . ).

...... . . ............... . . .... .. .. . .. . .. .. ... . . . . . .... . .... ...

| | |
|---|---|
| Chairman, Sub-committee for the American Society of Agronomy. | In charge of Register for the U. S. Bureau of Plant Industry. |

Approved, Sub-committee on Registration of Corn,

C. M. WOODWORTH (1930)
P. C. MANGELSDORF (1931)
F. D. RICHEY (1929), *Chairman.*

J. Allen Clark presented the report of the Sub-committee on the Registration of Oats, and, upon motion, the report was accepted.

REGISTRATION OF OAT VARIETIES

During the past year applications for the registration of six improved varieties were received by the sub-committee on the registration of oats. Of this number five were approved for registration by the sub-committee and also by the general committee on varietal standardization. The varieties are Brunker, Rainbow, Anthony, Miami, and Wayne. A record of their performance appears elswehere in this number of the JOURNAL (page 1175). Certificates of registration have been presented to the institutions and officials submitting the improved varieties for registration.

E. F. GAINES
H. H. LOVE
T. R. STANTON, *Chairman.*

J. Allen Clark, Chairman, presented the report of the Sub-committee on the Registration of Wheat, which, upon motion, was accepted.

### REGISTRATION OF WHEAT VARIETIES

The sub-committee for the registration of wheat varieties has received applications for three varieties during the past year. These have all been approved by both the sub-committee and the general committee on varietal standardization. The varieties are Purkof, Tenmarq, and Hawvale. A manuscript has been prepared giving the record of their performance, in comparison with that of standard varieties, and appears in this number of the JOURNAL (page 1172). Certificates of registration are being prepared for these new varieties.

J. H. PARKER
L. R. WALDRON
J. A. CLARK, *Chairman.*

J. B. Wentz read the report of the Committee on Crops Teaching Methods, which was accepted.

### CROPS TEACHING METHODS

The committee is making a study of the organization and content of courses in field crops as they are now being presented by the Land Grant Colleges. A questionnaire was sent to each of the colleges asking for information to be used in this study. The returns from these questionnaires are being tabulated and summarized and will be presented to the Society at a later date.

Dr. F. E. Bear, Chairman, presented the report of the Committee on Fertilizers and the report was accepted.

### FERTILIZERS

Pursuant to a request of the National Fertilizer Association, the Committee on Fertilizers during the year 1928–29 has devoted its attention chiefly to a consideration of the matter of quality of crop as affected by fertilizers. A survey of the American literature was attempted and a statement was prepared in which the several quality factors for each of the major crops were given attention.

This statement, not being complete in any sense and lacking specific suggestions as to investigational work along this line which might be undertaken to advantage, the Committee requests permission of the Society to mimeograph its report on this subject, without expense to the Society, and distribute it among the members of the Society and the various fertilizer companies to the end that some assistance may be had from those concerned in securing further references and suggestions for a final report to be submitted a year hence.

The Committee's report for 1927–28 gave consideration to two other matters concerning which it again desires to call the attention of the Society. One of them had to do with the "decimal-triangle" system of choosing fertilizer ratios for purposes of recommendation to farmers and fertilizer producers. This system is now being employed by the states of Michigan, Wisconsin, Missouri, Illinois, Indiana, Ohio, West Virginia, Maine, New Hampshire, Massachusetts, Rhode Island, and Connecticut. It is again commended for consideration by other states which have not as yet adopted the principle involved in its use.

The other matter previously reported on was that of the publication by the Society of a *Journal of Fertilizer Science*. It seems that there is as yet considerable doubt about the advisability of this being undertaken. The Committee is

of the opinion that this project should be kept before the Society and hopes that the idea will not be discarded until it has been given very careful consideration. The Committee is of the opinion that some such publication will, in due time, be desirable and that it should be published under the auspices of the Society.

Respectfully submitted,
A. B. BEAUMONT
J. W. GILMORE
J. C. PRIDMORE
FIRMAN E. BEAR, *Chairman.*

Dr. Emil Truog, Chairman, presented the report of the Committee on Fertilizer Distributing Machinery which was accepted.

## FERTILIZER DISTRIBUTING MACHINERY

The Committee on Fertilizer Distributing Machinery of the American Society of Agronomy, working in cooperation with the Joint Committee, has continued its work as follows:

I. A test of cotton fertilizer distributing machinery was made at the Sandhills Substation, South Carolina, and also at Clemson, South Carolina, through the cooperation of the U. S. Bureau of Public Roads, the U. S. Bureau of Soils and Chemistry, the South Carolina Experiment Station, and the National Fertilizer Association. A report of this test is to be published later.

II. A test of corn planter fertilizer distributing machinery was made at Madison, Wisconsin, through the cooperation of the Wisconsin Agricultural Experiment Station and the National Fertilizer Association. A report of the test has been published in *Agricultural Engineering*, 10: No. 10, 1929.

III. Continuing the work started last year, the Committee, the past year, secured the cooperation of 12 state experiment stations in carrying on a cooperative experiment on methods of fertilizer application to corn. A report of this work is to be made available.

IV. Prof. J. R. Fain, of the Committee, has prepared a detailed outline of principles and factors involved in field experiments on application and placement of fertilizers for cotton. A copy of this outline is appended.

V. It is recommended that a Committee be again appointed for next year.

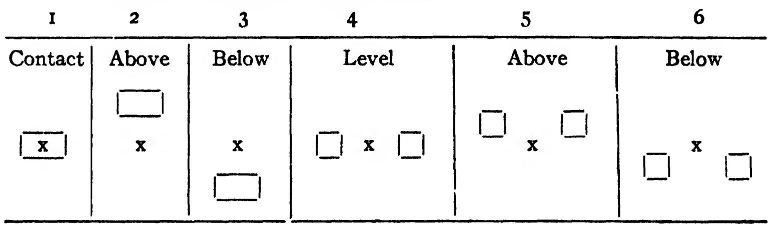
J. R. FAIN
F. E. BEAR
S. B. HASKELL
EMIL TRUOG, *Chairman.*

## REVISED TENTATIVE OUTLINE OF FIELD EXPERIMENT ON METHODS OF FERTILIZER APPLICATION

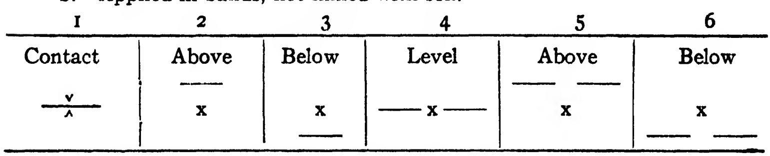
1. Climatic section. Southern states—weather records of the season to be kept and reported.
2. Kind of crop. Cotton—a variety common to the region is to be used. Where possible a pure strain of the variety is to be preferred.
3. Purpose of using fertilizer. Promote early growth, increase yields, and hasten maturity. Report whether one or all of them are desired.
4. Kind of soil to be used. A typical soil of the region is to be used, the nature of which is to be reported.

5. Method of applying.
   a. It would seem that most of the fertilizer used in the future will be applied by machinery in conjunction with some other operation, such as making beds, planting, and cultivating.
   b. The methods adopted will probably apply the fertilizer in furrows from the end of a spout, or in bands of different widths, or by one of these two methods with additional mixing with the soil.
   c. With reference to the seed, the placement may be: Above, in contact, below, on one or both sides, or surrounding.
6. A study of the effect of the concentration of the fertilizer secured with different methods, with different amounts of fertilizer, on different soil types is desirable.
7. Probable methods of application by machinery in drill rows are as follows in which x represents seed and squares and lines represent fertilizer.

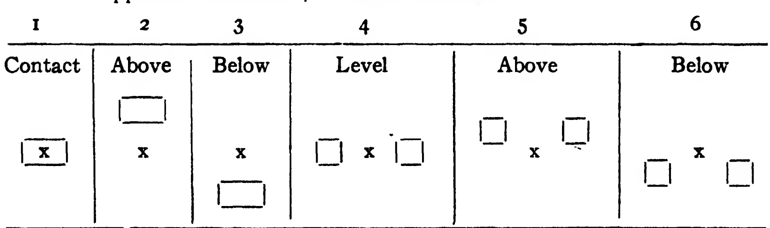
a. Applied in furrows, not mixed with soil.




b. Applied in bands, not mixed with soil.




c. Applied as in a and b, but mixed with soil.




8. In many soil types, placement No. 2 is undesirable because the fertilizer will not come into contact with sufficient moisture.
9. In all placements, the fertilizer should be in contact with soil moisture.
10. Distance of fertilizer placement from the seed will vary with soil type. It is suggested that the distance be from 1 to 3 inches from the seed. The distance adopted should be reported.
11. It is better to select a width of band that will give the desirable concentration for a given soil type than to adopt a definite and fixed width which is to be used in all cases.

12. It is suggested that the rates of fertilizer application per acre be 250, 500, 750, and 1,000 pounds, in order to conform to work in other parts of the United States.
13. Additional tests with larger amounts may be desirable, under certain conditions, such as 2,000 or 3,000 pounds, in order to define the limits that can be used for a particular soil type.
14. It is suggested that one method of placement, such as a or b, be used for a comparison of a to c with Nos. 1, 3, 4, and possibly others.
15. Effect on germination and early growth are to be especially noted.
16. The fertilizer should be adapted to soil type involved. A majority of the southern agronomists suggest a 10–4–4. It is suggested that the nitrogen be supplied in three forms, *viz.*, one-fourth as nitrate nitrogen, one-half as ammonical nitrogen, and one-fourth as organic nitrogen.

J. R. Fain.

G. H. Cutler presented the report of the Joint Committee with the International Crop Improvement Association and upon motion the report was accepted.

### TERMINOLOGY OF SEED OF IMPROVED VARIETIES

The Committee on Terminology of Seed of Improved Varieties, working jointly with a committee representing the International Crop Improvement Association, has continued its studies during the past year. After canvassing the opinion of plant breeders and agronomists regarding terms and definitions of the same, an attempt has been made to bring together and define those terms which seem to meet with greatest favor.

In making recommendations the committee wishes to emphasize that an effort has been made to adhere closely to minimum essentials, to take a genetic point of view, and to keep all the main staple farm crops in mind, including small grains, grasses, legumes, corn, cotton, tobacco, and rice.

Two main classes of seed are recommended, *viz.*, *Registered* and *Certified*. The former will probably represent the highest class of seed in circulation. Because of its high purity and quality, the supply of this class of seed will obviously be limited. Certified seed, on the other hand, will constitute the great bulk of seed to find its way into commerce. In many instances it will take its origin in registered seed. In fact, as seed improvement programs become better developed, certified seed should more and more trace back to registered seed.

Another term, namely, *Foundation Stock Seed*, is being recommended. This designates seed in that transition period following the breeding and selection stage and from which registered seed is derived.

There seems to be much general opposition on the part of plant breeders and agronomists to the inclusion of the term "elite." It is felt that this term is not essential and that its usage is not easily understood by farmers and seedsmen.

The recommended terms are defined as follows:

*Foundation Stock Seed.*—Foundation stock seed constitutes the traceable progeny of a variety or strain produced by individual plant, head, or pod selection, or mass selection of plants, heads, or pods, or by controlled self pollination and cross pollination followed by selection, of recorded origin, in the hands of the original breeder or experiment station, or their legal successors. Foundation stock seed must be in the hands and under the direct control of the original breeder, or a delegated representative of a state seed improvement association, or state or federal agricultural experiment station. By direct control is meant

that the seed must be grown on land owned or operated directly by the originators of the variety or strain, whether individual farmer, seedsman, or station, or a delegated successor.

*Registered Seed.*—Registered seed shall be defined as seed of a variety or strain which is the multiplied progeny of foundation stock seed. Such seed will be standardized in accordance with standards of purity and quality laid down by the state seed improvement association, agricultural extension service, and state or federal agricultural experiment station.

*Certified Seed.*—Certified seed shall be defined as seed of a variety or strain approved by the state or federal agricultural experiment station, certified as to purity, quality, and suitability, in accordance with standards laid down by the state seed improvement association, agricultural extension service, and state agricultural experiment station.

It will at once be apparent that the Committee is recommending a term which is now used to apply to a variety of crop. The term *registered* is here referred to. The committee feel, however, that there are at least two very good reasons for using this term to apply also to a class of seed. First, the International Crop Improvement Association adopted it a number of years ago, with the result that its usage is now pretty well understood by farmers and seedsmen. Second, it seems to carry a peculiar connotation of meaning, indicating as it does a superiority in purity and quality due to breeding and selection which lends value to its use when applied to a class of seed.

Other terms were considered by the committee in an attempt to develop a well-rounded out terminology, but sufficient unanimity had not been reached at this time to present a report.

The Committee recommends that this report be accepted and that the work of the Committee be continued.

Respectfully submitted,
O. W. Dynes
F. A. Bussell
R. A. Moore
Clyde McKee
G. H. Cutler, *Chairman.*

L. E. Call, Chairman, read the report of the Joint Committee on Corn Borer Investigations and the report was accepted.

## EUROPEAN CORN BORER INVESTIGATIONS

The European corn borer has continued its natural spread since its discovery in America in 1917. Its average rate of advance to the South and West has been from 25 to 30 miles per year. In 1929 it occupied 10,000 to 12,000 square miles of new territory in the United States. It now occurs throughout the southern portion of Quebec and Ontario, as well as locally in New Brunswick and Nova Scotia in Canada, the southern two-thirds of New England, the northern extremity of New Jersey, all of New York, three-fourths of Pennsylvania and Ohio, the Panhandle of West Virginia, nearly all of the agricultural portion of Michigan and the northeastern fourth of Indiana. It has now reached the threshold of the main Corn Belt.

The corn borer is only thinly distributed over the newly infested territory and causes no apparent injury. It increases in numbers rather slowly at first and, judging from past experience, will not cause evident injury in the first 2 to 4

years. This provides a period during which the entire community should obtain and apply the latest recommended control measures. In most of the older infested areas the borer has increased greatly in numbers. Where this insect has been established for several years, commercial damage to corn now occurs unless natural factors have checked the borer temporarily or adequate control measures have been applied. If this is true in the eastern edge of the Corn Belt, where most of the corn is cut and much of it put in the silo, thus simplifying an adequate clean-up, how much more will it be true in the main Corn Belt where most of the stalks are left in the field?

It, therefore, is still the opinion of the Joint Committee that, unless the corn borer is controlled, it will become one of the most destructive crop pests ever introduced into America. The situation, presenting as it does, the possibility of enormous agricultural losses, calls for the continued cooperation of the farmer, the scientist, the educator, and all State and Federal administrative officials.

The cooperating committee of entomologists, agronomists, agricultural engineers, agricultural economists, and animal husbandmen, most heartily endorses all endeavors to control the corn borer, and commends the efforts of all farmers practicing control measures and all persons engaged in the research, regulatory, and educational activities.

The committee recognizes the necessity for the continued development of the research, educational, and quarantine programs of the State and Federal Governments and earnestly recommends the appropriation of the funds necessary to maintain these activities, and expand them when necessary,

After careful and complete investigation of the corn-borer regulatory, research, and educational activities, the committee suggests and recommends:

1. That since the quarantine efforts have been successful in preventing long-distance spread by artificial means, and since the only known spread of any importance in the United States has been by the natural flight of the corn-borer moths or by water drift of infested material, the quarantine activities of the Federal Governments of the United States and Canada should be supported and encourgaed by the States and Provincial Agricultural Colleges and Experiment Stations, the State Departments of Agriculture, and all other agencies interested in the welfare of American agriculture.

2. That because the clean-up in certain of the infested areas has not been complete and the borer population is increasing, quarantine action is much more imperative.

3. That scouting should be continued in the areas contiguous to known infested areas and extended to the larger corn-producing States where areas seem particularly exposed to infestation. Ample funds should be available for a thorough cleanup of isolated infestation in such areas.

4. That two primary methods of control of the corn borer are recognized, namely, (a) the utilization or destruction of all host plant remnants each year, and (b) the somewhat later planting of corn. To facilitate the first of these methods labor saving tools and farm machinery should be devised or improved as rapidly as possible.

5. That gratifying progress in European Corn Borer research has been made during the past year. Certain phases have already yielded results from which conclusions of both practical and technical value have been drawn. On the other hand, the committee wishes to emphasize the necessity for continued effort in each of the major lines of entomology, agronomy, agricultural engineering, agricultural economics and animal husbandry. While certain lines of work have served their purpose and should be discontinued along with those that have been found unfruitful, there are still many problems requiring continued study as well as others yet unattacked and it is urged that future emphasis be given these. In addition, the committee suggests that all major phases be expanded so far as practicable, into corn-belt States not yet infested with the borer.

Respectfully submitted.

American Association of Economic Entomologists

G. A. DEAN — D. J. CAFFREY
L. CAESAR — J. J. DAVIS
C. J. DRAKE

American Society of Agronomy

L. E. CALL — J. F. COX
W. L. BURLISON — R. M. SALTER
F. D. RICHEY

American Society of Agricultural Engineers

C. O. REED — A. L. YOUNG
S. H. MCCRORY — R. B. GRAY
R. D. BARDON

American Farm Economic Association

C. R. ARNOLD — H. M. C. CASE
O. G. LLOYD — A. G. BLACK
C. L. HOLMES

American Society of Animal Production

E. W. SHEETS — PAUL GERLAUGH
F. G. KING — G. A. BROWN
F. B. MORRISON

Dr. C. R. Ball, representative of the Society in the Division of Biology and Agriculture of the National Research Council, reported on matters of interest to the Society. The report was accepted.

## REPORT OF THE REPRESENTATIVE ON THE NATIONAL RESEARCH COUNCIL

Two activities of the National Research Council during the year should be of interest to members of this Society.

In 1928, several investigators, headed by Dr. W. C. Curtis of the University of Missouri, petitioned the Division of Biology and Agriculture to appoint a committee on the effects of radiation upon living organisms, with authority to obtain funds for these projects. Such a committee was created, with Dr. Curtis as chairman. Contributions of funds and apparatus thus obtained have made it possible for the committee to award grants in aid of research in this field, totaling about $30,000, exclusive of a considerable quantity of expensive apparatus.

The Pan-American Union, the cooperating organization of the Republics of the three Americas, asked the Department of State to suggest a scientific adviser to the recently established Division of Agricultural Cooperation in the Union. The State Department in turn asked the National Research Council to act in that capacity and the Council designated its Division of Biology and Agriculture as such scientific adviser. The Division has appointed the Pan-American Union Advisory Committee with the following personnel: Dr. William Crocker, *Chairman*, Dr. Carlos Chardon, Dr. B. T. Galloway, and Dr. A. F. Woods. The Committee is engaged in making arrangements for a conference of the interests concerned, to be held in Washington during the summer of 1930. It is hoped that important results leading to cooperation and coordination may be attained.

CARLETON R. BALL

## NOMINATING COMMITTEE

Dr. R. W. Thatcher, Chairman, presented the report of the Nominating Committee as follows:

For President—Dr. W. P. Kelley of California

For 4th Vice-President—Prof. George Stewart of Utah

For Representative on the Council of the A.A.A.S.—Dr. J. B. Wentz of Iowa and Dr. W. H. MacIntire of Tennessee.

Upon motion the Secretary cast the unanimous ballot of the Society for these officers and they were declared elected.

## RESOLUTIONS

S. B. Haskell, Chairman, presented the report of the Committee on Resolutions, which upon motion, was accepted. The report follows:

## RESOLUTIONS

In view of the death on November 10th of Dr. E. W. Allen, for many years Chief of the Office of Experiment Stations of the United States Department of Agriculture, and for many years a friend of all members of the American Society of Agronomy, it is hereby resolved

THAT the American Society of Agronomy expresses its sense of deep loss and bereavement arising from the death of Dr. Allen.

In his passing the cause of true research in the service of American agriculture loses a powerful champion and the American Society of Agronomy a friend who has done valiant service in raising the standards of research in the agronomic sciences to their present levels.

The Society regrets that its members may no longer have the benefit of Dr. Allen's careful and constructive criticisms of agronomic research. At its annual meetings the Society will miss the participation of one qualified to speak because of training, experience, and successful service; and one who has become a master of forceful and direct expression in the English language.

The Society feels that while Dr. Allen's work will go on, since it was built on a strong and lasting foundation, yet the place which he has occupied in the hearts of those who knew him, through working with him, can never be filled.

The Society expresses its thanks and appreciation:

1. To President Funchess, for the able leadership exercised during the year just closing, and to his cooperators who arranged the excellent and valuable programs of the twenty-second annual meeting of the Society;

2. To J. D. Luckett for the efficiency with which the JOURNAL has been edited and managed;

3. To Dr. P. E. Brown for the continuation during the year of those many services which have contributed so greatly to the standing and prestige of the Society; and

4. To the Management of the Stevens Hotel for the hospitality shown, and the fine accommodations given the Society on the occasion of its annual meeting.

GEORGE ROBERTS
C. G. WILLIAMS
SIDNEY B. HASKELL, *Chairman.*

## SECOND INTERNATIONAL SOIL CONGRESS

Dr. A. G. McCall announced the Second International Congress of Soil Science to be held next year in Russia and explained briefly the plans for the Congress:

Dr. J. G. Lipman discussed the Congress, calling attention to the many interesting features which have been planned. He also presented the matter of promoting an endowment fund to support the work of the International Society of Soil Science. He reported that $3,000 had already been secured and suggested that the American Society of Agronomy act as trustee of the fund. Upon motion, the suggestion was referred to the Executive Committee for action.

## EXTENSION PROGRAM

Dr. C. W. Warburton spoke of the desirability of having an Extension program at the alternate meetings of the Society held in Washington, and also of the Exposition to be held in Chicago in 1933.

## LAND GRANT COLLEGE MEETINGS

Dr. R. W. Thatcher announced that the Association of Land Grant Colleges would begin its meetings on Monday next year, thus avoiding any conflict with the meetings of the agronomists.

Meeting adjourned.

P. E. Brown, *Secretary.*

## PROGRAM

THURSDAY, NOVEMBER 14

8:30 A.M.—SOCIAL HOUR

9:30 A.M.—MEETING CALLED TO ORDER

President M. J. FUNCHESS

APPOINTMENT OF COMMITTEES

1. Initiating and executing agronomic research
   E. W. ALLEN, Office of Experiment Stations
2. Is it desirable for agronomy to train its own research workers?
   W. C. COFFEY, University of Minnesota
3. The function of the U. S. Department of Agriculture in the state program of agronomic research
   M. A. McCALL, Bureau of Plant Industry
   M. F. MILLER, University of Missouri
4. Impressions of European soil Conferences of 1929
   S. A. WAKSMAN, University of New Jersey

## Crops Sectional Program

THURSDAY, NOVEMBER 14

2:00 P.M.

SYMPOSIUM: "SOME ALFALFA PROBLEMS"

Leader: R. I. THROCKMORTON, Kansas State Agricultural College

1. Alfalfa problems past and present
   GEORGE STEWART, Utah Agricultural College
2. Winter hardiness of alfalfa
   L. F. GRABER, University of Wisconsin
3. Root reserves of alfalfa and their relation to time of cutting and yield
   C. J. WILLARD, Ohio State University

   Discussion: Led by A. C. Arny, University of Minnesota
4. Bacterial wilt of alfalfa
   FRED R. JONES, Bureau of Plant Industry
5. A progress report of alfalfa root rot research
   J. J. TAUBENHAUS, Texas A. & M. College

## Soils Sectional Program

THURSDAY, NOVEMBER 14

2:00 P.M.

SYMPOSIUM: "PHOSPHORUS"

Leader: F. C. BAUER. University of Illinois

1. The census as an aid in mapping soils deficient in phosphorus
   C. A. MOOERS, University of Tennessee
2. The variability of soil response to applied phosphates
   E. E. DETURK, University of Illinois

3. The effects of associated soil treatments on the availability of applied phosphates to field crops on different soil types
GEO. ROBERTS, University of Kentucky

4. The distribution and solubility of native and applied phosphates in the various soil separates of certain Kentucky soils
M. C. FORD, University of Wisconsin

5. Some aspects of the absorption of phosphates by plants bearing on soil fertilization
D. R. HOAGLAND, University of California

6. The phosphorus content of the soil solution and its relation to plant growth
J. W. TIDMORE, Alabama Polytechnic Institute

7. The determination of available phosphorus in soils
E. TRUOG, University of Wisconsin

THURSDAY, NOVEMBER 14

6:30 P.M.

Annual Dinner—Stevens Hotel

PRESIDENT'S ADDRESS:

"SOME OUTSTANDING RESULTS OF AGRONOMIC RESEARCH AND THE VALUE OF SUCH CONTRIBUTIONS"
M. J. FUNCHESS, Alabama Polytechnic Institute

BUSINESS MEETING
Officers' Reports
Committee Reports
Election of Officers
New Business
Announcements

## Crops Sectional Program

FRIDAY, NOVEMBER 15

8:30 A.M.

1. Weed investigations in relation to the production and marketing of farm seed
H. C. RATHER, Michigan State College

2. Controlling perennial weeds with chlorates
H. W. HULBERT, University of Idaho

3. The growth of kudzu as influenced by supplies of organic foods
W. H. PIERRE, University of West Virginia

4. The importance of food reserves in the growth of sweet clover
C. J. WILLARD, Ohio State University

5. Organic foods and the growth behavior of Bahia grass
W. A. LEUKEL, University of Florida

6. Food storage in Johnson grass
D. G. STURKIE, Alabama Polytechnic Institute

7. Hardiness in relation to some of the organic constituents of winter wheat
GEORGE JANSSEN, University of Arkansas

8. Organic constituents of the cotton plant in relation to its fruiting habits
W. B. ALBERT, Clemson Agricultural College
9. Relation of organic foods to the growth of western pasture plants
A. E. ALDOUS, Kansas State Agricultural College
10. Organic food reserves and agronomic research
L. F. GRABER, University of Wisconsin

## Soils Sectional Program

FRIDAY, NOVEMBER 15

8:30 A.M.

1. Experiment station dealing with peat soils
F. J. ALWAY, University of Minnesota
2. Phases of work in peat investigations
A. P. DACKNOWSKI-STOKES, Bureau of Chemistry and Soils
3. The rôle of sulfur in plant nutrition
W. L. POWERS, Oregon Agricultural College
4. The use of small amounts of lime in the row
M. M. MCCOOL, Michigan State College

FRIDAY, NOVEMBER 15

2:00 P.M.

1. The juices of corn plants as an indicator of fertilizer needs
N. A. PETTINGER, Virginia Polytechnic Institute
2. A progress report on pasture fertilization based on demonstrations conducted in 1928 and 1929
JOHN B. ABBOTT, National Fertilizer Association
3. Objectives and methods in soils research
V. E. SPENCER, University of Nevada
4. Crop returns from the use of fertilizers based on estimates by farmers
H. R. SMALLEY, National Fertilizer Association
5. The moisture saving efficiency of level terraces under semi-arid conditions
H. H. FINNELL, Panhandle A. & M. College
6. Some phases of water logged soil conditions
W. O. ROBINSON, Bureau of Chemistry and Soils
7. The effect of soil colloids on the efficiency of superphosphate
PHILIP L. GUILE, Bureau of Chemistry and Soils
8. Some biological aspects of the decomposition of green manures
HARRY HUMFELD and N. R. SMITH, Bureau of Chemistry and Soils
9. The assimilation of nitrogen by tobacco
A. B. BEAUMONT, Massachusetts Agricultural College
10. The nature of the base exchange material of soils
W. P. KELLEY, University of California

11. Plant characters as indices in relation to the ability of corn strains to withstand lodging

H. K. WILSON, University of Minnesota

12. The use of advanced-generation hybrids as parents of double-crossed seed corn

T. A. KIESSELBACH, University of Nebraska

## OFFICERS OF THE SOCIETY FOR 1930

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J. D. LUCKETT, *Editor*
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## STANDING COMMITTEES FOR 1930

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C. R. Ball, *Chairman*
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C. A. Shull

### STANDARDIZATION OF FIELD EXPERIMENTS

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H. H. Love

### VARIETAL STANDARDIZATION AND REGISTRATION

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### EDUCATION IN AGRONOMY

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Henry Dorsey
H. O. Buckman
O. W. Dynes

### CHILEAN NITRATE OF SODA NITROGEN RESEARCH AWARD

S. A. Waksman (1932), *Chairman*
R. W. Thatcher (1930)
C. B. Williams (1930)
R. I. Throckmorton (1931)
Richard Bradfield (1932)
W. P. Kelley (1931)

### FERTILIZERS

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M. F. Miller
George Roberts
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## SIXTEENTH ANNUAL MEETING OF THE NEW ENGLAND SECTION

An interesting and well attended meeting of the New England Section of the Society was held at the Hotel Kimball, Springfield, Mass., Nov. 29 and 30. The meeting was called to order at 2 P.M., Nov. 29, by Chairman Dorsey, and the afternoon session was devoted to a consideration of experiment station work, with reports of work in progress at the various stations made by the following: Maine, G. E. Simmons; New Hampshire, F. S. Prince; Vermont, E. Van Alstine (read by the Secretary); Massachusetts, J. P. Jones; Rhode Island, T. E. Odland; Connecticut (New Haven), M. F. Morgan; Connecticut (Storrs), B. A. Brown; and Connecticut (Windsor), P. J. Anderson. Short reports were also made by C. F. Noll and F. P. Bussell.

Directors Sievers, Gilbert, and Slate, of the Massachusetts, Rhode Island, and Connecticut Stations, respectively, discussed the topic, "A Constructive Program of Research for New England." Director Sievers spoke on the problem of the research worker, Director Gilbert on work that should receive attention, and Director Slate on ways of organization for the promotion of the work. Some 60 station agronomists and men with commercial connections were present at this session.

The program of the evening session, which began with a banquet attended by 55, included a paper on "The Trend of Agronomic Research in New England," by Henry M. Steece of the Office of Experiment Stations of the U. S. Dept. of Agriculture; a talk by Director Sievers on his European trip of the past summer; and a "Progress Report on Pasture Demonstrations," by J. B. Abbott. The informal part of the evening meeting was in the nature of a discussion of the points raised by the three directors in the afternoon. It was voted to continue the committee on lime with a view to better cooperation with the commercial interests concerned.

The morning session on the 30th was called to order at 9:20 A.M. by Chairman Dorsey, who briefly outlined the origin of the committee work on varietal recommendations and seed sources. The meeting was then turned over to J. S. Cwens, leader of the symposium on this topic. C. F. Noll of the Pennsylvania Station reported on "Small Grains," D. F. Jones of Connecticut on "Corn," T. E. Odland of Rhode Island on "Clover," and A. B. Beaumont of Massachusetts on "Alfalfa." Considerable discussion was aroused and valuable contributions were made by the representatives of the Eastern States Farmers' Exchange. Following the symposium, F. P. Bussell of the Department of Plant Breeding, Cornell University, presented a paper on "Use Adaptations of Small Grains."

At the business meeting it was voted to continue the committees on varieties with J. S. Cwens as general chairman. Chairman Dorsey announced the appointment of the following committee on cooperation and coordination of experiment station work: T. E. Odland, *chairman*, B. A. Brown, A. B. Beaumont, E. Van Alstine, F. S. Prince, and G. E. Simmons.

Prof. Beaumont, reporting for the committee on the New England Standard Nine, recommended that agronomists should unite in working on the best ratios for various crops, that the ratio idea be maintained, and that a 1–2–2 ratio be established as soon as economically feasible. The report was accepted.

Chairman Dorsey appointed the following committee on by-laws and constitution: J. P. Jones, *chairman*, A. B. Beaumont, and G. E. Simmons. On recommendation of the nominating committee T. E. Odland and G. E. Simmons were elected to form, with the chairman of the section, an executive committee, to serve in advisory capacities. The present officers, Henry Dorsey, *chairman*, and M. H. Cubbon Secretary, were reelected for the coming year.—M. H. CUBBON, *Secretary*.

## NEWS ITEMS

H. N. WATENPAUGH, for two years graduate assistant in soil technology at Penn State, working for his doctor's degree, resigned on September 1 to accept the position of Assistant Professor of Soils at the New Mexico College of Agriculture and Mechanical Arts at State College, New Mexico. He took up his duties there on September 1.

A. H. PASCHALL, for some time Assistant in Soils at the Ohio Agricultural Experiment Station, has been appointed Graduate Assistant in Soil Technology at Penn State and entered upon his duties September 1. He will give half time to graduate studies leading to an advanced degree.

T. J. HARRISON for many years Professor of Agronomy at the College of Agriculture, University of Manitoba, Winnipeg, has resigned his position to become Assistant Grain Commissioner for the district of Manitoba, Board of Grain Commissioners, Dominion Department of Trade and Commerce.

G. F. H. BUCKLEY, who has just completed his graduate work at the University of California and secured the degree of Ph.D. has accepted a position with the Dominion Experimental Farm, Brandon, Manitoba, as Agrostologist. Dr. Buckley's work at the University of California was on the genetics of barley.

A. T. ELDERS, Agrostologist at the Dominion Experimental Farm, Brandon, has resigned his position to accept the position of Assistant Professor of Agronomy, specializing in plant breeding, at the College of Agriculture, University of Manitoba.

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